

# Assessing the effect of water meter installation on exposure to lead in water

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# Assessing the effect of water meter installation on exposure to lead in water


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# Glossary

| | |
|---|---|
| 30-MS | 30 minute stagnation sample |
| RDT | Random daytime sample |
| TOC | Total organic carbon |

# Summary


## i Reasons

This project investigated the effect of the installation of water meters in lead pipes on the lead concentration in drinking water.

Lead service pipes that connect water mains to customers' premises are the principal source of lead in drinking water in the UK. Phosphate dosing and/or pH adjustment are used in water treatment to control plumbosolvency, forming an insoluble layer on the internal surface of the pipes which can maintain the concentration of lead below the 10 µg/l UK standard. Installation of a water meter (or similar fitting) into a lead pipe is expected to disturb the protective layer, potentially causing a transient increase in lead concentration. Due to metered supplies becoming more common it was important to gain a better understanding of such effects.

## ii Objectives

- To understand the likely impact of the installation of a water meter (or similar fitting), to a property supplied through a lead pipe, on potential for increased exposure to lead via drinking water.

- In the event that consumers are subject to increased exposure as a result of installation activities, to identify possible actions and/or advice to companies and/or consumers to reduce the risk.

## iii Benefits

This project elucidates the potential extent and duration of an increase in the concentration of lead in drinking water following the installation of a water meter (or similar fitting) in an existing lead pipe and identifies possible actions to mitigate the risk of increased exposure to lead by the consumer in these circumstances.

## iv Conclusions

The overarching conclusion form this study is that installation of meters or other fittings into lead pipes can lead to transient increases in lead concentration in the water. These elevated concentrations, mainly of particulate lead, can last for about 3 days and can be effectively removed by flushing.

### Pipe rig trials

- Total lead concentration in drinking water increased to a concentration substantially greater than the regulatory standard (10 µg/l) following the installation of water meters in test pipes. Values of up to 278 µg/l in first flush samples and 419 µg/l in 30-MS samples were recorded for tests *without* induced air disturbance. Values of up to 612 µg/l in first flush samples and 286 µg/l in 30-MS samples were recorded in tests *with* induced air disturbance.

- The increase in lead concentration was principally due to particulate material.

- The increase in lead concentration was reduced substantially by flushing, and total and dissolved lead concentrations were reduced to approximate pre-installation values (<10 µg/l) after the passage of 900-2,700 litres of water, equivalent to 3-9 days of typical domestic water use for a household of 2 people.

### Field trials

- Installation of a water meter to old lead supply pipes resulted in a subsequent temporary increase in the concentration of total lead in the water supply. The degree of increase varied substantially between the sites monitored, peaking at between 573 and 9,700 µg/l. The observed increases were markedly greater than those observed in the controlled pipe rig tests. The reasons for this are most probably a combination of the age of the lead pipes in the field study, with associated accumulations of lead compounds on the pipe wall, together with the greater disturbance as a result of manual manipulation of pipes in the process of meter installation.

- The degree of increase in total lead concentration did not to appear to be consistently related to the degree of pipe disturbance, indicating that other factors were also important.

- The concentration of dissolved lead also increased subsequent to the meter installation, but to a far lesser degree, peaking at between 5 and 22 µg/l.

- For the 2 sites where a 100 litre flush was applied on Day 0, total lead concentration measured less than 10 µg/l in the final samples taken on Day 0.

- The total concentration of lead remained at less than 10 µg/l in both the RDT and 30-MS samples taken on Days 1, 3 and 8 after meter installation, at the 3 properties where this was measured, with a single sample exception. This represented a volume of between 200 and 400 litres used between meter fitting on Day 0 and sampling on Day 1.

- Flushing of the water supply to waste immediately following installation of a water meter into an old lead supply pipe is clearly an effective method of reducing the potential for customer exposure to elevated concentration of lead. The flushing requirement will depend upon a range of factors:

  - Internal pipe condition
  - Degree of manipulation of the pipe during installation
  - Degree of disturbance during repairs to the ground around the newly installed boundary box
  - Length of the supply pipe.

- Very limited tests using a proprietary jug type water filter indicated that this could be an effective additional temporary measure, in the week following the installation, to further reduce the total and dissolved concentration of lead in water.

## v Suggestions

### Post installation flushing regime

Where the installer determines that the service pipe is lead, the consumer should be informed of this fact and offered the standard company advice on lead pipes. In addition they should be advised to flush their cold water supply immediately following the installation, for a minimum of 10 minutes, and to flush again for 2 minutes at the first use of the kitchen tap, for the next 3 days.

# 1. Introduction

## 1.1 Objectives

The overall objectives of the project were:

- Understand the likelihood of potential increased exposure to lead via drinking water following the installation of a water meter (or similar fitting) where a property is supplied through a lead pipe.

- In the event that consumers are subject to increased exposure as a result of installation activities, to identify possible actions and/or advice to companies and/or consumers to reduce the risk.

The overall objectives were achieved in two stages:

Stage 1 – Pipe rig trials: Investigation of the release of lead resulting from the installation of water meters to lead pipes on a pipe rig sited at WRc. The trials were carried out with soft and hard phosphate-dosed waters to investigate:

- Trial 1 – Installation of water meters using a 'high disturbance' procedure.

- Trial 2 – Installation of water meters using a 'low disturbance' procedure.

- Trial 3 – Effect of air/water turbulence during flushing following installation of the water meter.

Stage 2 – Field investigations: Subsequent to the pipe rig trials, field investigations were carried out at customers' premises to monitor the effect of the installation of water meters to lead pipes in practice. Concentrations of lead in drinking water were measured immediately before and after installation, and for a further period of time.

## 1.2 Background

Lead in drinking water is a recognised health concern. The World Health Organisation (WHO) has progressively tightened its guideline value for lead from 100 µg/l to the current 10 µg/l. European lead standards have been similarly tightened and in the UK the PCV (prescribed concentration or value) for lead in drinking water was reduced from 25 µg/l to 10 µg/l on 25 December 2013.

The principal source of lead in drinking water is lead service pipes; lead-based solders (used historically but now banned); brass fittings can be a contributory source.

Phosphate dosing and/or pH adjustment are currently used to control plumbosolvency. Phosphate dosing is effective and has reduced lead concentrations in drinking water by 90% since its introduction in the 1990s. Phosphate reacts with the surface of the lead pipe to form a protective lead phosphate layer that has very low solubility. However, this protective layer can be compromised chemically – as a result of a change in the phosphate dose affecting the chemical equilibrium – or mechanically – through a physical disturbance to the pipe.

The physical disturbance caused by the installation of a water meter (or similar fitting) to a lead pipe could increase the lead concentration in the drinking water. The concentration of both particulate and dissolved lead could increase, particularly where the pipe is cut and a fresh lead surface is revealed.

An increasing frequency of meter installations in older properties over the next few years could therefore result in an increase in compliance failures.

WRc was commissioned to investigate the impact of the installation of water meters on the lead concentration in drinking water where properties are supplied through lead pipes and, where increased exposure may result, to provide advice for water companies and/or consumers to reduce the risk.

## 1.3 Programme of Work

The programme of work considered the installation of the most common water meters used in England and Wales, simulating a typical installation technique observed in the field. A comprehensive pipe rig test programme was used to identify the magnitude and duration of any increase in lead concentration and the nature of the lead (particulate or dissolved) arising from the installation. This was followed by a field study of the effects of meter installation at properties with lead pipes.

## 1.4 Résumé

This final report describes the first ('high disturbance') and second ('low disturbance') water meter installation trials carried out on the lead pipe rig between July and October 2013, the third trial investigating the effect of air/water turbulence carried out between April and July 2014 and the outcome of the field studies described above .

- Section 2 describes the water meter installation trials on the lead pipe rig, and presents and discusses the results of these tests.
- Section 3 describes the field trials carried out at customers' premises, and presents and discusses the results of this study.
- Sections 4 and 5 present the conclusions and suggestions, respectively.

# 2. Lead Pipe Rig Trials

## 2.1 Introduction

A lead pipe rig was designed and built to investigate the effects of installing water meters on lead concentrations in drinking water. The test rig comprised of 8 new lead pipes, 4 of which were pre-conditioned with a hard water, and 4 were pre-conditioned with a soft water. The flow through the pipes was controlled by a programme, allowing a profile of different periods of flow, to simulate a real household. Further details of the lead pipe rig and its operation are given in Appendix A.

## 2.2 Initial stabilisation of the lead pipes

Phosphate-dosed (target 2 mgP/l) water was fed to each of the lead pipes. After approximately six month's operation with intermittent pipe flow rates of 6 l/min (total daily flow per pipe = 360 l), the effluent lead concentrations had stabilised as follows:

- Hard water (Pipes 1-4): total lead 5-7 µg/l, dissolved lead 4-6 µg/l and particulate lead 1-2 µg/l (with occasional peaks).
- Soft water (Pipes 5-8): total lead 2 µg/l, dissolved lead 0.4-0.8 µg/l and particulate lead 0.5-1.0 µg/l (with occasional peaks).

It was noted that the concentration of dissolved lead was significantly less for the soft water compared to the hard water – contrary to general experience – whilst the particulate lead concentrations for both waters were comparable (about 0.5-2.0 µg/l with occasional peaks).

## 2.3 Trial 1 – Simulation of 'high disturbance' installation of a water meter

Following the initial stabilisation period, an ATPLAS boundary box with an Elster V210 plastic-bodied water meter[1] was installed in each of six lead pipes on 18 July 2013. Three water meters were installed in 'hard water' pipes (Pipes 1, 2 and 3) and three in 'soft water' pipes (Pipes 6, 7 and 8). One 'hard water' pipe (Pipe 4) and one 'soft water' pipe (Pipe 5) were left without a water meter, to act as controls.

The installation procedure simulated that witnessed at a UK water utility, including simulation of the disturbance caused by the use of a petrol-driven low vibration breaker.

[1] This combination of boundary box and water meter was identified as commonly installed in England and Wales.

### 2.3.1 Preparation of Rig

The two control pipes were strapped to supports along their length (to prevent flexing), plugged at both ends and carefully removed from the vicinity of the lead pipe rig so as to be unaffected by the vibration in the meter installation procedure.

A box containing backfill material (216 mm depth) with a tarmacadam finish (64 mm depth) was bolted to a leg of the lead pipe rig, approximately 90 mm from floor level. A 6.5 mm thick metal plate was located between the tarmacadam and backfill layers to disperse vibration radially; a gap of 25 to 50 mm between the plate and the sides of the box prevented direct transmission of vibration. A low-vibration breaker was operated in the box for a specified period[2], striking against a 6.5 mm metal plate located on the surface of the tarmacadam to distribute the load and prevent destruction of the tarmacadam layer. The box was relocated to the opposite side of the rig and the procedure repeated.

The lead pipes were cut at their inlet ends using low-compression pipe shears and the boundary box/water meters installed. The installation left the freshly cut pipe ends, either side of the water meter, in contact with water.

Installation of the water meters reduced the length of lead pipe from 3.00 m to approximately 2.70 m (volume approximately 257 ml).

The control pipes were reinstated and the pipe rig flow programme was restarted. Samples of effluent were taken for lead analysis and particle counts as per the schedule described below.

### 2.3.2 Sampling and Analysis

#### Pre-installation

Sample 1: First-flush sample from each pipe after 8-h stagnation period, analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

Sample 2: 30-MS sample from each pipe, analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

[2] A test run confirmed gentle vibration of the lead pipes. It was decided to operate the breaker for 60 seconds on either side of the rig.

## Immediately following installation

Sample 3: Operate rig at 6 l/min (normal rate) and collect 1 litre of effluent from each pipe (approx. 3.5 pipe volumes (10 seconds flow)), analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

Sample 4: 30-MS sample from each pipe (approx. 0.8 pipe volume), analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

Sample 5: Operate rig at 6 l/min (normal rate) and collect 1 litre of effluent from each pipe (approx. 3.5 pipe volumes (10 seconds flow)), analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

Sample 6: 30-MS sample from each pipe (approx. 0.8 pipe volume), analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

Sample 7: Operate rig at 6 l/min (normal rate) and collect 1 litre of effluent from each pipe (approx. 3.5 pipe volumes (10 seconds flow)), analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

Sample 8: 30-MS sample from each pipe (approx. 0.8 pipe volume), analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

## Post-installation

Sampling post-installation was carried out as described below or continued until effluent lead concentrations had stabilised.

Run pipe rig as per normal flow regime.

- Week 1 (1-day following installation): First-flush sample from each pipe after 8-h stagnation period, analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

- Week 1 (1-day following installation): 1x 30-MS sample from each pipe, analysed for lead (total and filtered) and particle counts. (8x total Pb, 8x filtered Pb)

- Week 1 (3-days following installation): 1x 30-MS sample from each pipe, analysed for lead (total and filtered). (8x total Pb, 8x filtered Pb)

- Week 2 (7-days following installation): 1x 30-MS sample from each pipe, analysed for lead (total and filtered). (8x total Pb, 8x filtered Pb)

- Week 3 (14-days following installation): 1x 30-MS sample from each pipe, analysed for lead (total and filtered). (8x total Pb, 8x filtered Pb)
- Week 4 (21-days following installation): 1x 30-MS sample from each pipe, analysed for lead (total and filtered). (8x total Pb, 8x filtered Pb)
- Week 5 (28-days following installation): 1x 30-MS sample from each pipe, analysed for lead (total and filtered). (8x total Pb, 8x filtered Pb)
- Week 6 (35-days following installation): 1x 30-MS sample from each pipe, analysed for lead (total and filtered). (8x total Pb, 8x filtered Pb)

**Table 2.1 Summary of sampling and analysis schedule**

| Sample | Cumulative pipe volume (litres) | Sample description | No. Lead analyses | |
|---|---|---|---|---|
| | | | Total | Dissolved |
| Pre-installation | | | | |
| 1 | - | 8-hour stagnation sample | 8 | 8 |
| 2 | - | 30-MS sample | 8 | 8 |
| Immediately following installation | | | | |
| 3 | 3.5 | 1 litre flush sample (3.5 pipe volumes) | 8 | 8 |
| 4 | 4.3 | 30-MS sample (0.8 pipe volume) | 8 | 8 |
| 5 | 7.8 | 1 litre flush sample (3.5 pipe volumes) | 8 | 8 |
| 6 | 8.6 | 30-MS sample (0.8 pipe volume) | 8 | 8 |
| 7 | 12.1 | 1 litre flush sample (3.5 pipe volumes) | 8 | 8 |
| 8 | 12.9 | 30-MS sample (0.8 pipe volume) | 8 | 8 |
| Post installation | | | | |
| Week 1 | 161 | 8-hour stagnation sample (Day 1) | 8 | 8 |
| Week 1 | 604 / 3130 | 2x 30-MS sample (Day 1 / Day 3) | 16 | 16 |
| Week 2 | 9449 | 2x 30-MS sample (Day 8) | 8 | 8 |
| Week 3 | 18,291 | 1x 30-MS sample (Day 15) | 8 | 8 |
| Week 4 | 27,133 | 1x 30-MS sample (Day 22) | 8 | 8 |
| Week 5 | 35,975 | 1x 30-MS sample (Day 29) | 8 | 8 |
| Week 6 | 44,817[(2)] | 1x 30-MS sample (Day 36) | 8 | 8 |

Notes:

1. Cumulative pipe volumes based volume of control pipe (285 ml) and sample volume (220 ml).
2. Minimum, as continued until effluent lead concentrations stabilised.

### Particle counts

Particle counts were made on discrete sub-samples of pipe effluents taken for lead analysis and measured in size ranges up to 50 µm. However, as particles greater than 10 µm accounted for less than 5% of the particle counts measured, only counts in the ranges 2-<5 µm (80-85% of the particle counts) and 5-<10 µm (10-15%) have been reported.

## 2.3.3 Trial 1 Results

### Feed water analysis

Analyses of the hard and soft feed waters are shown in Figure 2.1 and Figure 2.2, respectively.

**Figure 2.1 Water quality during Trials 1 – 3 (Hard water feed)**

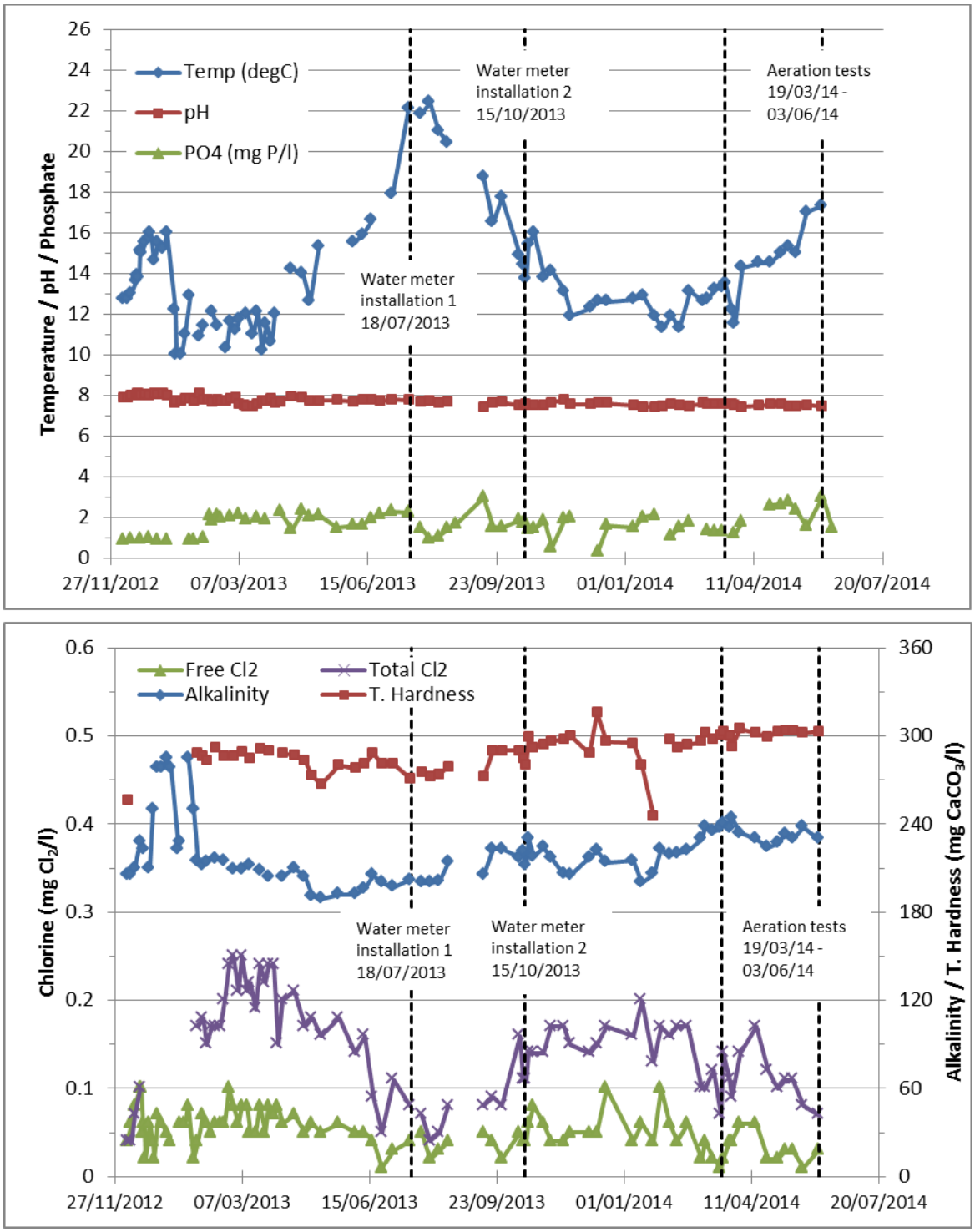
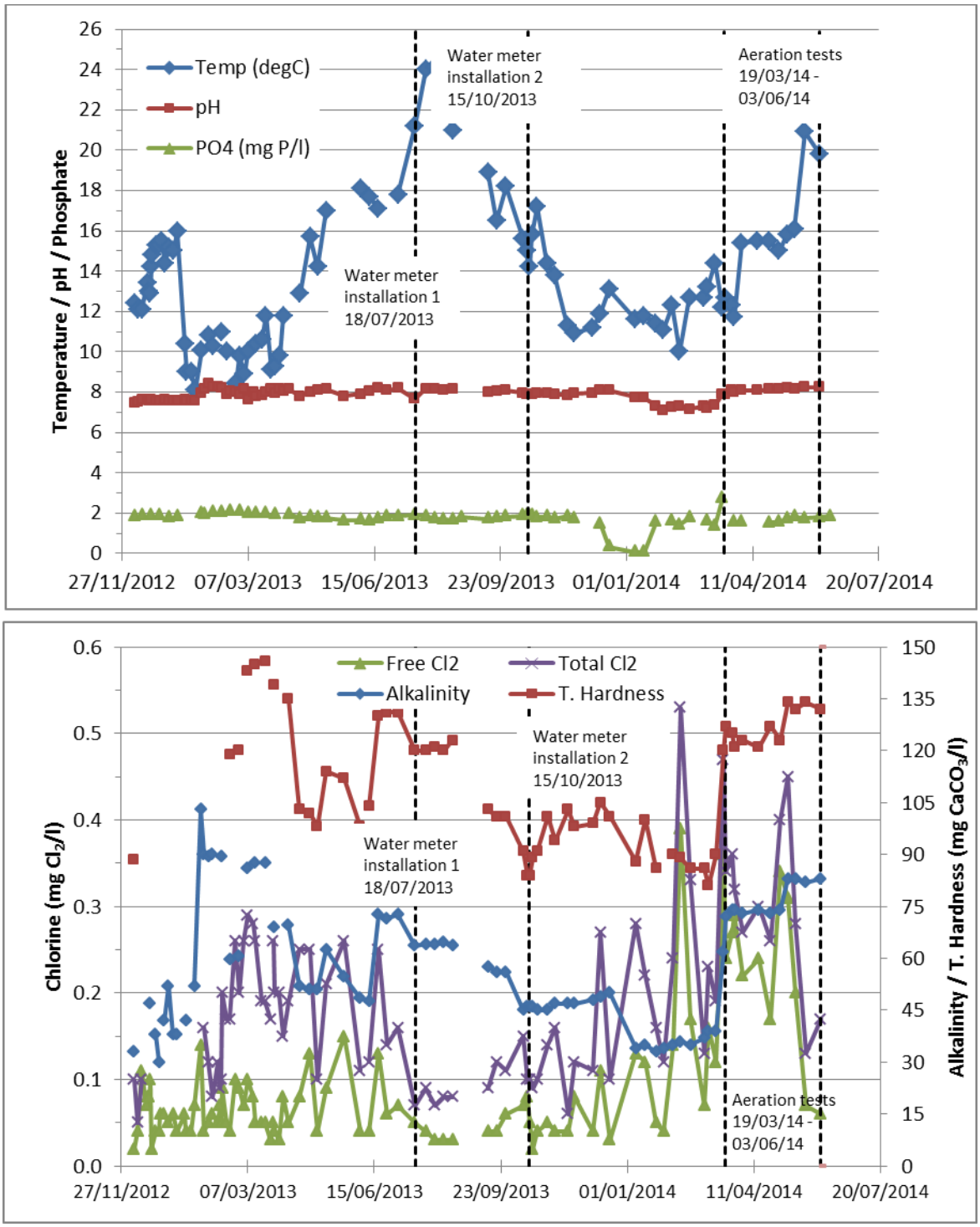


**Figure 2.2 Water quality during Trials 1 – 3 (Soft water feed)**



## Pipe effluent analysis

Effluent lead concentrations in samples taken from the hard water pipes are shown in Table 2.2, Figure 2.3 and Figure 2.4; corresponding particle counts are shown in Table 2.3 and Figure 2.5.

Effluent lead concentrations in samples taken from the soft water pipes are shown in Table 2.4, Figure 2.6 and Figure 2.7; corresponding particle counts are shown in Table 2.5 and Figure 2.8.

**Table 2.2 Trial 1 – Lead analyses for pipes with hard water**

| Sample (Date) | Sample type | Cum. flow | P1[1] Total lead | P1[1] Diss. lead | P2[1] Total lead | P2[1] Diss. lead | P3[1] Total lead | P3[1] Diss. lead | P4(c)[2] Total lead | P4(c)[2] Diss. Lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-installation** | | | | | | | | | | |
| 1 (17/07) | 8-HS | - | 21.6 | 17.4 | 19.4 | 15.4 | 14.5 | 11.5 | 24.7 | 13.4 |
| 2 (17/07) | 30-MS | - | 7.8 | 7.1 | 8.2 | 7.3 | 6.2 | 5.6 | 6.8 | 5.6 |
| **Immediately following installation** | | | | | | | | | | |
| 3 (18/07) | 1-L flush | 1 | 68.4 | 6.1 | 19.6 | 6.5 | 106.0 | 4.7 | 44.9 | 6.8 |
| 4 (18/07) | 30-MS | 1.22 | 54.4 | 16.5 | 37.7 | 15.5 | 42.7 | 8.6 | 71.6 | 17.1 |
| 5 (18/07) | 1-L flush | 2.22 | 17.1 | 11.7 | 18.0 | 11.8 | 23.0 | 10.0 | 20.1 | 11.4 |
| 6 (18/07) | 30-MS | 2.44 | 29.2 | 16.7 | 21.5 | 15.8 | 21.9 | 11.6 | 54.6 | 19.0 |
| 7 (18/07) | 1-L flush | 3.44 | 11.3 | 8.5 | 10.1 | 7.7 | 11.7 | 6.8 | 14.8 | 7.7 |
| 8 (18/07) | 30-MS | 3.66 | 27.3 | 16.0 | 18.8 | 15.1 | 18.5 | 11.7 | 29.7 | 17.5 |
| **Post-installation** | | | | | | | | | | |
| 9 (19/07) | 8-HS | 63.9 | 29.4 | 22.2 | 23.5 | 20.2 | 18.7 | 14.1 | 29.3 | 16.2 |
| 10 (19/07) | 30-MS | 172 | 18.3 | 9.8 | 9.9 | 9.1 | 8.8 | 7.3 | 21.2 | 7.4 |
| 11 (21/07) | 30-MS | 892 | 12.3 | 7.7 | 7.9 | 7.2 | 8.2 | 5.5 | 8.3 | 3.1 |
| 12 (26/07) | 30-MS | 2,693 | 12.0 | 9.2 | 10.2 | 8.5 | 8.4 | 6.8 | 9.8 | 6.8 |
| 13 (02/08) | 30-MS | 5,213 | 22.9 | 19.6 | 19.0 | 16.4 | 16.9 | 14.0 | 19.1 | 16.0 |
| 14 (09/08) | 30-MS | 7,733 | 19.0 | 16.8 | 19.5 | 14.7 | 14.9 | 12.8 | 17.0 | 13.1 |
| 15 (16/08) | 30-MS | 10,253 | 13.0 | 10.7 | 11.5 | 9.5 | 9.9 | 8.3 | 13.1 | 8.1 |
| 16 (23/08) | 30-MS | 12,773 | 12.8 | 9.9 | 10.4 | 9.1 | 9.2 | 8.3 | 11.7 | 8.7 |

**Notes:**

1. Pipes 1,2 and 3: Pipe length = 2.7 m; pipe volume = 257 ml; sample volume = 220 ml (sample time = 2.5 s).
2. Pipe 4 (control): Pipe length = 3.0 m; pipe volume = 285 ml; sample volume = 220 ml (sample time = 2.5 s).

**Figure 2.3 Trial 1 – Effluent lead concentration pre- and post-installation (30-MS samples, hard water, time basis)**

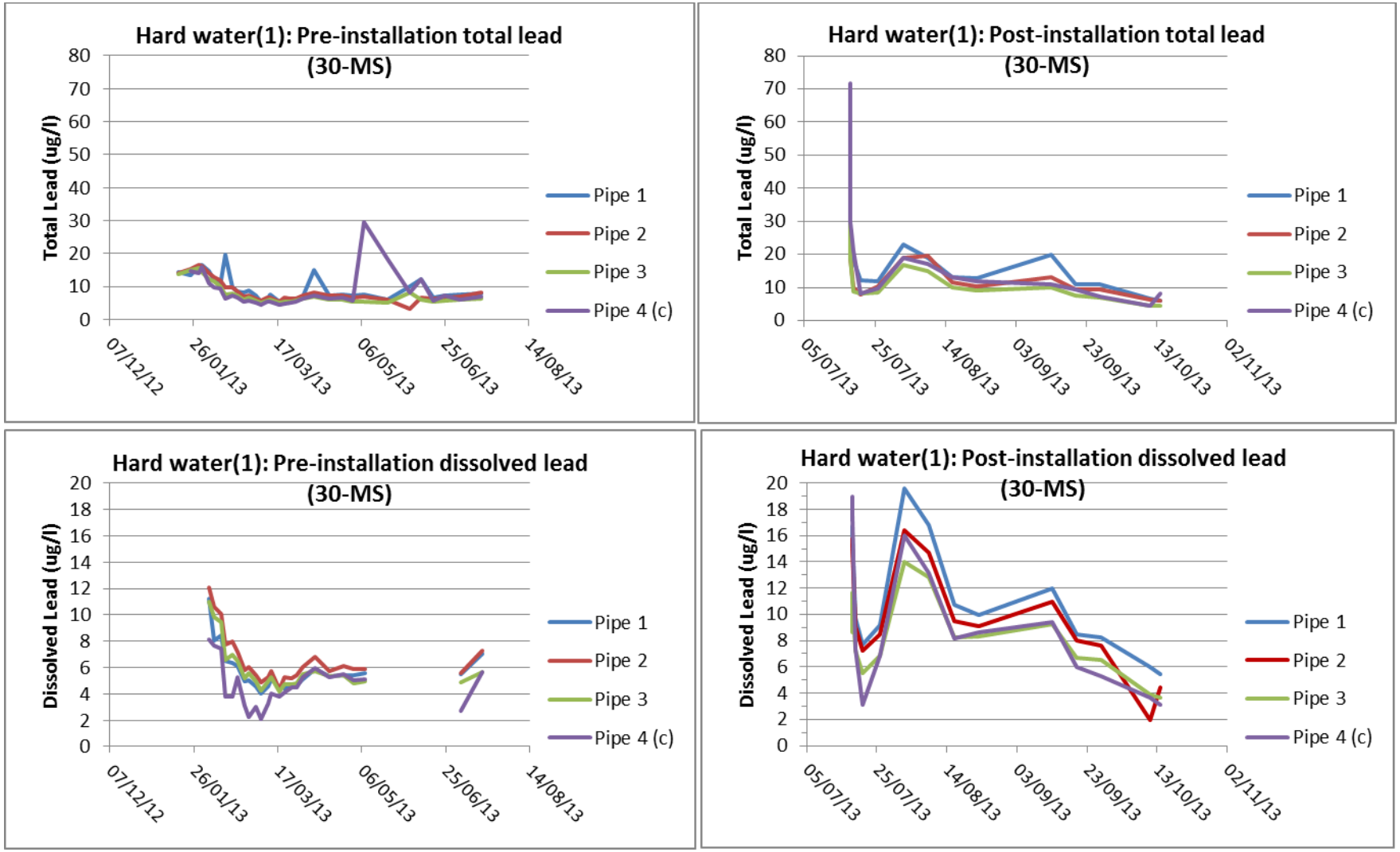


**Figure 2.4 Trial 1 – Effluent lead concentration Pre- and post-installation (30-MS samples, hard water, volume basis)**

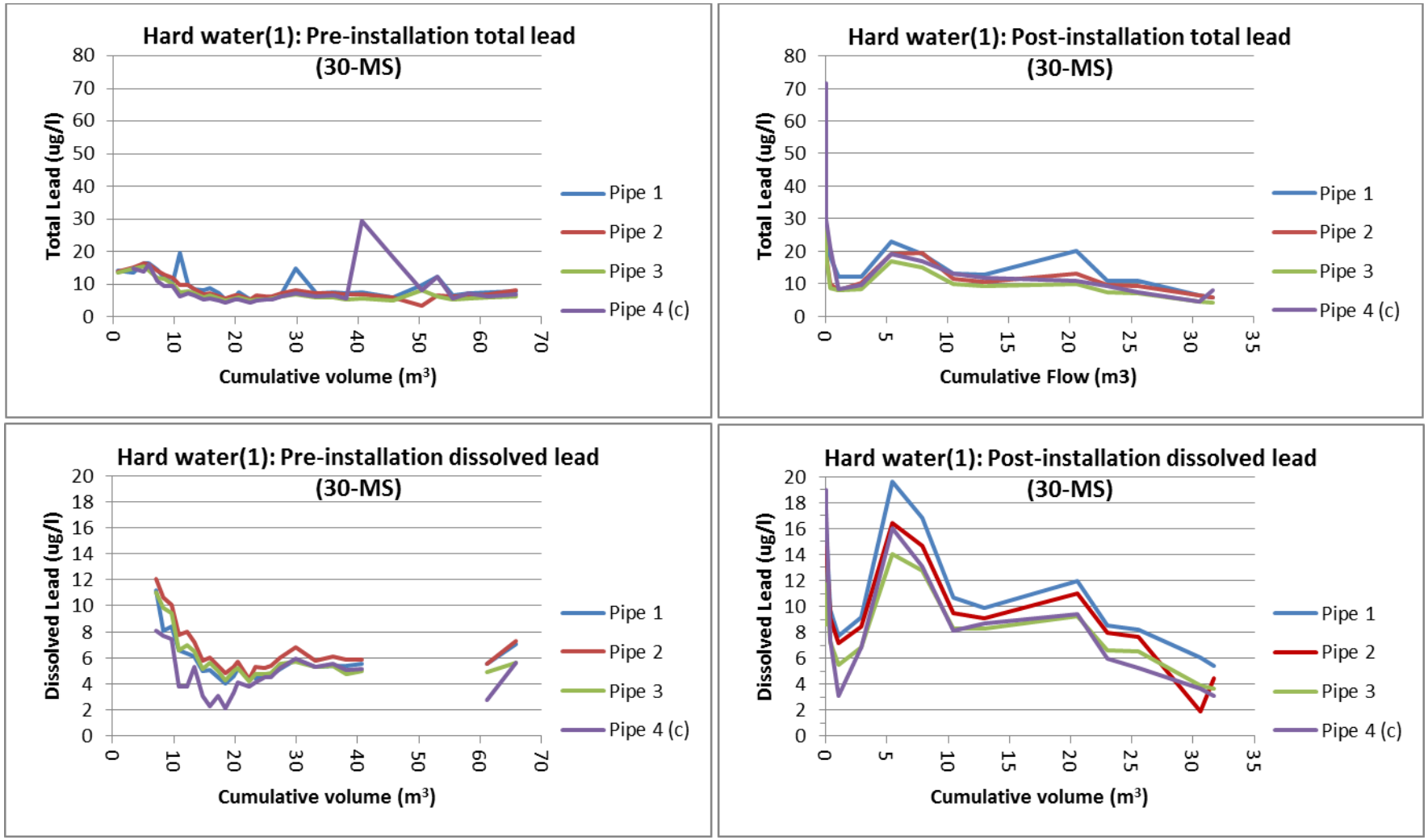


**Table 2.3 Trial 1 – Feed and effluent particle counts for pipes with hard water**

| Sample (Date) | Sample type | Feed (Counts /ml) | | P1 (Counts /ml) | | P2 (Counts /ml) | | P3 (Counts /ml) | | P4(c) (Counts /ml) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm |
| **Pre-installation** | | | | | | | | | | | |
| 1 (17/07) | 8-HS | 267 | 57 | 250 | 53 | 261 | 38 | 540 | 113 | 932 | 182 |
| 2 (17/07) | 30-MS | 267 | 57 | 264 | 45 | 236 | 35 | 327 | 52 | 498 | 81 |
| **Immediately following installation** | | | | | | | | | | | |
| 3 (18/07) | 1-litre flush | - | - | 1944 | 553 | 2661 | 731 | 2259 | 626 | 1426 | 381 |
| 4 (18/07) | 30-MS | - | - | 828 | 220 | 899 | 224 | 1675 | 419 | 2456 | 604 |
| 5 (18/07) | 1-litre flush | - | - | 576 | 143 | 1221 | 339 | 972 | 246 | 1065 | 177 |
| 6 (18/07) | 30-MS | - | - | 647 | 166 | 936 | 212 | 1585 | 380 | 1405 | 334 |
| 7 (18/07) | 1-litre flush | - | - | 507 | 127 | 941 | 265 | 1004 | 282 | 855 | 172 |
| 8 (18/07) | 30-MS | - | - | 624 | 161 | 1167 | 294 | 1463 | 351 | 1380 | 314 |
| **Post-installation** | | | | | | | | | | | |
| 9 (19/07) | 8-HS | - | - | 429 | 119 | 473 | 122 | 652 | 160 | 1571 | 364 |
| 10(19/07) | 30-MS | - | - | 379 | 89 | 271 | 50 | 498 | 99 | 663 | 137 |
| 12(26/07) | 30-MS | 100 | 16 | 227 | 39 | 222 | 33 | 615 | 147 | 670 | 137 |
| 13(02/08) | 30-MS | 141 | 47 | 220 | 41 | 181 | 27 | 651 | 175 | 416 | 85 |
| 14(09/08) | 30-MS | 62 | 12 | 205 | 41 | 226 | 35 | 299 | 94 | 284 | 58 |
| 15(16/08) | 30-MS | 179 | 38 | 183 | 35 | 221 | 23 | 245 | 66 | 798 | 175 |

**Figure 2.5 Trial 1 – Feed and effluent particle counts (count/ml, for pipes with hard water)**

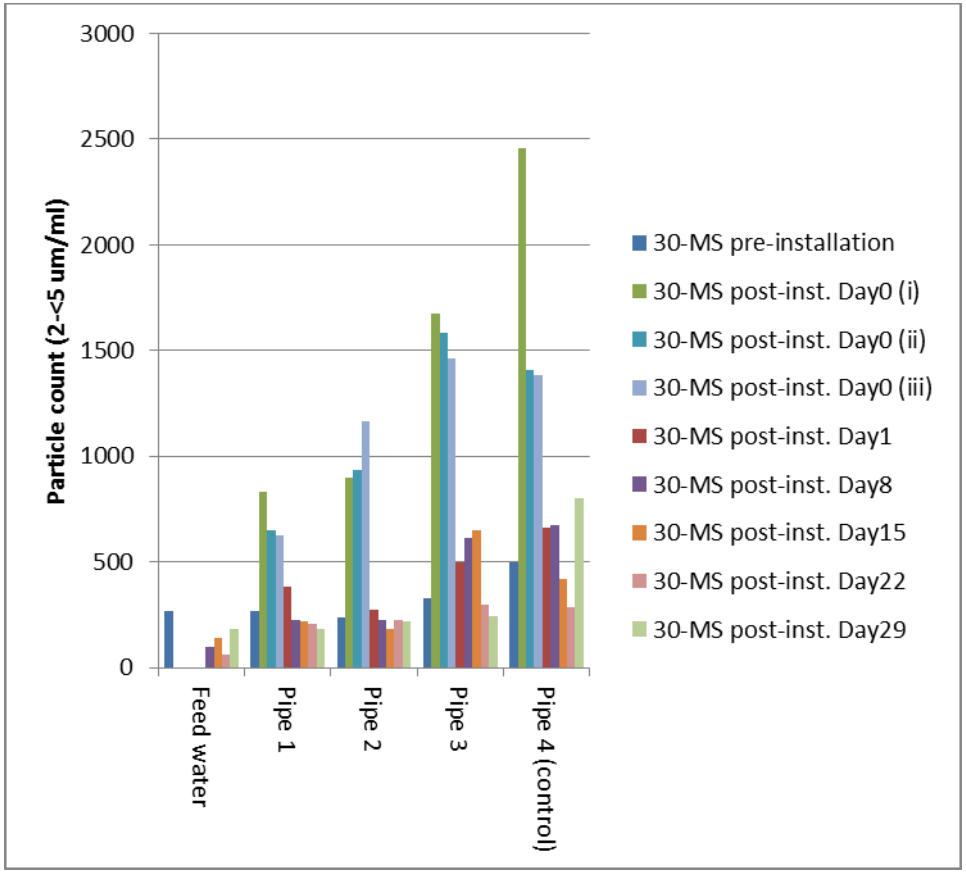


**Table 2.4 Trial 1 – Lead analyses for pipes with soft water**

| Sample (Date) | Sample type | Cum. flow | P5(c)[1] Total lead | P5(c)[1] Diss. lead | P6[2] Total lead | P6[2] Diss. lead | P7[2] Total lead | P7[2] Diss. lead | P8[2] Total lead | P8[2] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-installation** | | | | | | | | | | |
| 1 (17/07) | 8-HS | - | 5.08 | 2.85 | 7.08 | 3.43 | 8.20 | 4.59 | 4.23 | 3.14 |
| 2 (17/07) | 30-MS | - | 2.1 | 1.7 | 2.5 | 1.6 | 3.2 | 2.1 | 2.3 | 1.5 |
| **Immediately following installation** | | | | | | | | | | |
| 3 (18/07) | 1-L flush | 1 | 117 | 2.6 | 262 | 4.3 | 223 | 7.1 | 67.9 | 4.3 |
| 4 (18/07) | 30-MS | 1.22 | 109 | 3.0 | 419 | 3.1 | 48.4 | 3.8 | 14.8 | 2.8 |
| 5 (18/07) | 1-L flush | 2.22 | 6.6 | 2.3 | 22.7 | 2.0 | 8.9 | 3.0 | 8.5 | 2.7 |
| 6 (18/07) | 30-MS | 2.44 | 40.9 | 3.3 | 253 | 4.0 | 18.2 | 4.7 | 9.7 | 3.4 |
| 7 (18/07) | 1-L flush | 3.44 | 9.3 | 1.7 | 37.7 | 2.0 | 7.1 | 2.3 | 7.6 | 2.0 |
| 8 (18/07) | 30-MS | 3.66 | 37.0 | 3.2 | 81.7 | 3.6 | 25.7 | 4.9 | 11.0 | 3.4 |
| **Post-installation** | | | | | | | | | | |
| 9 (19/07) | 8-HS | 63.9 | 7.52 | 4.0 | 22.8 | 7.6 | 13.3 | 7.01 | 11.3 | 4.79 |
| 10 (19/07) | 30-MS | 172 | 2.8 | 2.1 | 25.5 | 3.7 | 15.0 | 3.6 | 5.2 | 2.5 |
| 11 (21/07) | 30-MS | 892 | 2.4 | 1.8 | 19.1 | 2.6 | 56.2 | 2.7 | 2.7 | 2.3 |
| 12 (26/07) | 30-MS | 2,693 | 3.8 | 1.2 | 13.0 | 2.2 | 13.1 | 1.9 | 2.4 | 1.3 |
| 13 (02/08) | 30-MS | 5,213 | 1.8 | 1.8 | 9.4 | 3.3 | 5.2 | 2.3 | 14.7 | 1.9 |
| 14 (09/08) | 30-MS | 7,733 | 1.5 | 1.8 | 4.9 | 2.6 | 5.3 | 1.6 | 4.1 | 1.6 |
| 15 (16/08) | 30-MS | 10,253 | 1.6 | 1.3 | 6.4 | 1.7 | 3.1 | 1.3 | 1.6 | 0.9 |
| 16 (23/08) | 30-MS | 12,773 | 2.0 | 1.8 | 4.8 | 1.4 | 6.2 | 1.1 | 1.5 | 0.7 |

Notes:

1. Pipe 5 (control): Pipe length = 3.0 m; pipe volume = 285 ml; sample volume = 220 ml (sample time = 2.5 s).
2. Pipes 6, 7 and 8: Pipe length = 2.7 m; pipe volume = 257 ml; sample volume = 220 ml (sample time = 2.5 s).

**Figure 2.6 Trial 1: Soft water - Pre- and post-installation 30-MS effluent lead concentrations (time basis)**

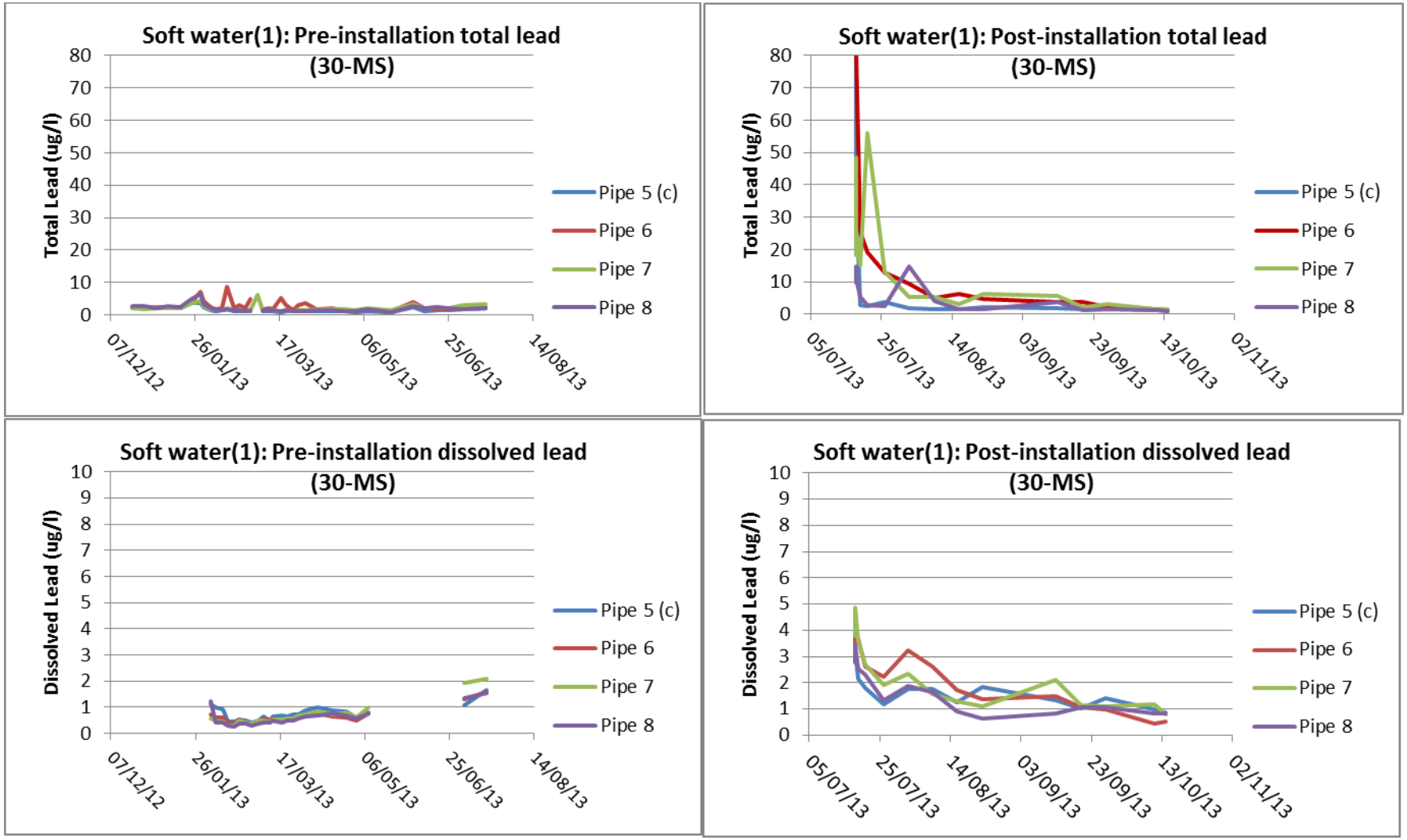


**Figure 2.7 Trial 1: Soft water - Pre- and post-installation 30-MS effluent lead concentrations (volume basis)**

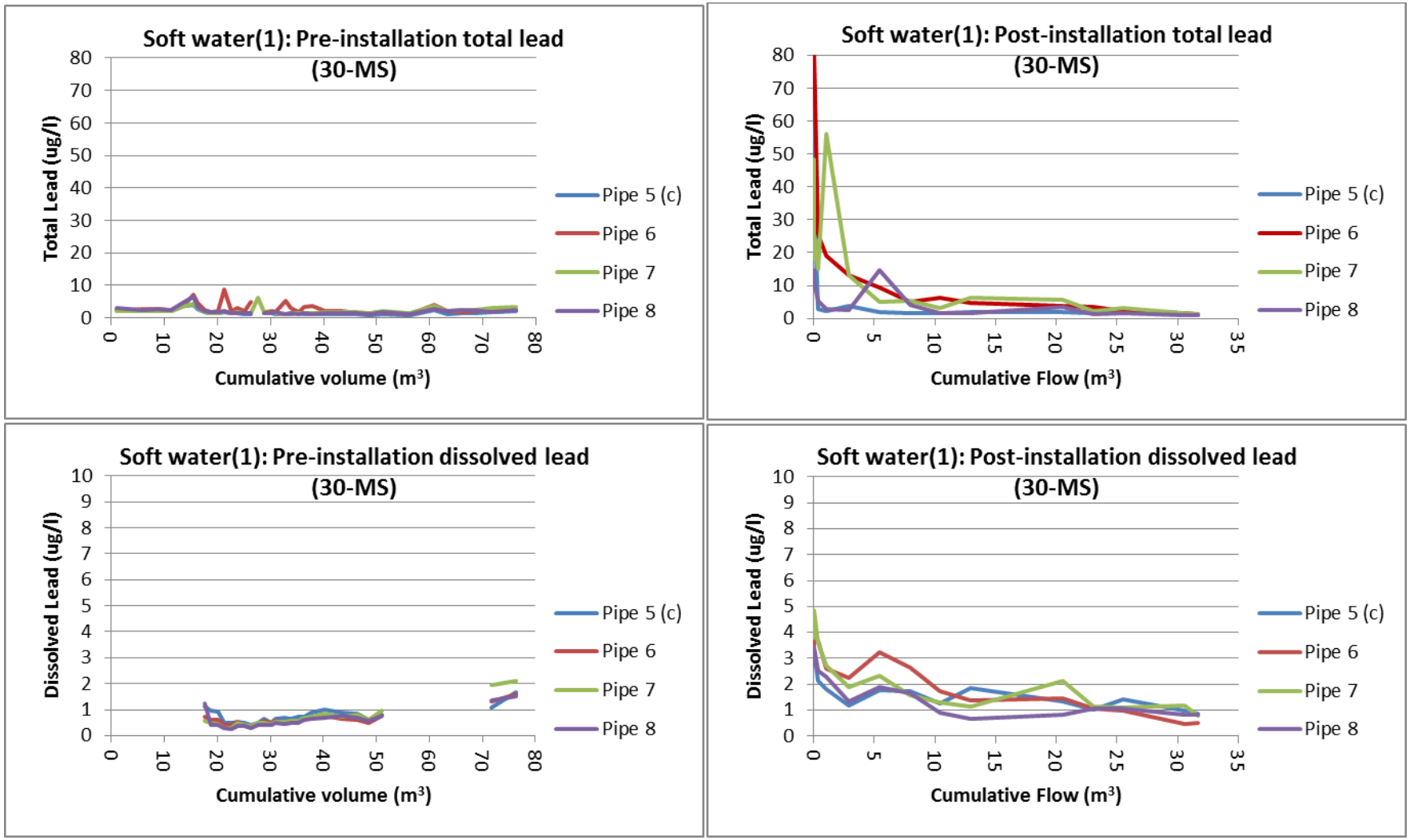
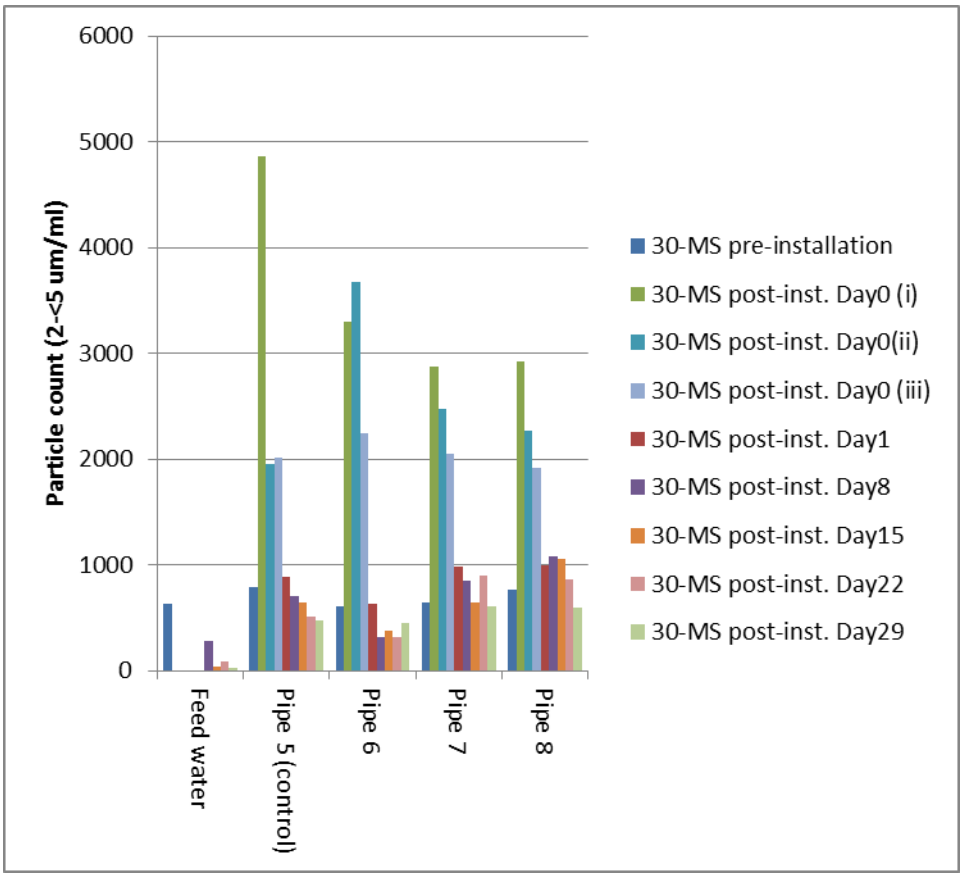


**Table 2.5 Trial 1 – Feed and effluent particle counts for pipes with soft water**

| Sample (date) | Sample type | Feed (Counts/ml) | | P5(c) (Counts/ml) | | P6 (Counts/ml) | | P7 (Counts/ml) | | P8 (Counts/ml) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm |
| **Pre-installation** | | | | | | | | | | | |
| 1 (17/07) | 8-HS | 634 | 91 | 916 | 262 | 668 | 168 | 1279 | 324 | 995 | 225 |
| 2 (17/07) | 30-MS | 634 | 91 | 789 | 154 | 605 | 118 | 641 | 132 | 760 | 129 |
| **Immediately following installation** | | | | | | | | | | | |
| 3 (18/07) | 1-litre flush | - | - | 871 | 2894 | 13636 | 3791 | 9132 | 3000 | 8150 | 2702 |
| 4 (18/07) | 30-MS | - | - | 4866 | 1546 | 3300 | 952 | 2874 | 862 | 2926 | 862 |
| 5 (18/07) | 1-litre flush | - | - | 2706 | 676 | 2547 | 603 | 2190 | 509 | 2105 | 482 |
| 6 (18/07) | 30-MS | - | - | 1947 | 519 | 3671 | 985 | 2473 | 699 | 2271 | 559 |
| 7 (18/07) | 1-litre flush | - | - | 2084 | 454 | 2170 | 460 | 2225 | 483 | 2235 | 508 |
| 8 (18/07) | 30-MS | - | - | 2016 | 546 | 2245 | 559 | 2053 | 533 | 1915 | 419 |
| **Post-installation** | | | | | | | | | | | |
| 9 (19/07) | 8-HS | - | - | 1653 | 379 | 54 | 128 | 1200 | 414 | 966 | 299 |
| 10(19/07) | 30-MS | - | - | 881 | 214 | 630 | 132 | 984 | 297 | 999 | 321 |
| 12(26/07) | 30-MS | 274 | 72 | 698 | 189 | 311 | 65 | 846 | 294 | 1076 | 330 |
| 13(02/08) | 30-MS | 36 | 10 | 647 | 278 | 372 | 95 | 640 | 198 | 1058 | 432 |
| 14(09/08) | 30-MS | 89 | 39 | 512 | 216 | 310 | 77 | 894 | 241 | 855 | 281 |
| 15(16/08) | 30-MS | 26 | 7 | 468 | 198 | 452 | 94 | 605 | 130 | 594 | 184 |

**Figure 2.8 Trial 1 – Feed and effluent particle counts (count/ml, for pipes with soft water)**



### 2.3.4 Trial 1 Discussion

#### Lead concentration from 'hard water' pipes

Pre-installation: Prior to the installation of the water meters, the concentration of total and dissolved lead in 30-MS samples from the test pipes measured 6.2-8.2 µg/l and 5.6-7.3 µg/l, respectively; the lead concentration in comparable samples from the control pipe measured 6.8 µg/l and 5.6 µg/l, respectively.

Immediately following installation: The concentration of total and dissolved lead in 1-litre flush samples from the test pipes measured 19.6-106 µg/l and 4.7-6.5 µg/l, respectively. The samples from the test pipes contained a large proportion of particulate lead (13.1-101.3 µg/l, 67-96% of the total lead concentration) as a result of the installation procedure. Although the control pipe was not exposed to the vibration caused by the breaker, the sample also contained a large proportion of particulate lead (38.1 µg/l, 85%) as a result of the disturbance in temporarily relocating the pipe.

Total lead concentrations in 1-litre flush samples taken from the test pipes after the passage of 13.2 pipe volumes (3.4 litres) of water reduced to 10.1-11.7 µg/l (particulate lead 2.4-4.9 µg/l). The comparable total lead concentration from the control pipe reduced to 14.8 µg/l (particulate lead 7.1 µg/l). These values indicate the potential for significantly reducing exposure to the increase in lead concentration as a result of flushing immediately following water meter installation.

The concentration of total and dissolved lead in the 30-MS samples taken from the test pipes immediately following installation increased to 37.7-54.4 µg/l and 8.6-16.5 µg/l, respectively, substantially greater than the pre-installation values. The comparable values from the control pipe also increased substantially, to 71.6 µg/l and 17.1 µg/l, respectively. The increase in the total lead concentration was largely due to particulate material, 22.2-37.9 µg/l (59-80% of the total lead concentration) from the test pipes and 54.5 µg/l (76%) from the control pipe.

The concentration of particulate lead in the 30-MS samples decreased with the continued passage of water. Concentrations from the test and control pipes reduced to 3.7-11.3 µg/l and 12.2 µg/l, respectively, following the passage of 3.4 litres of water. The dissolved lead concentrations were largely unaffected by the continued passage of water and remained relatively high, with the values from the test pipes (11.7-16.0 µg/l) comparable to that of the control pipe (17.5 µg/l).

Post-installation: The concentration of total and dissolved lead in the 30-MS samples from the test pipes approached pre-installation values after about 3 days, following the passage of 3,471 pipe volumes of water (892 litres). There was a subsequent increase in the

concentration of total and dissolved lead to 22.9 µg/l and 19.6 µg/l, respectively, 15 days[3] after the installation of the water meters.

A similar observation was made on Day 15 (02/08) for the control pipe, with the concentration of lead approaching pre-installation values after 3 days and a subsequent increase in total and dissolved lead concentrations to 19.1 µg/l and 16.0 µg/l, respectively.

As the increase in lead concentration after 15 days affected the effluents from the hard water pipes and, to a lesser extent, the effluents from the soft water pipes, it was initially postulated that the increase was due to a physical disturbance of the lead rig. A physical disturbance would be expected to initially increase the total lead largely through a transient increase in particulate material (arising from disturbance of the lead phosphate protective layer) with possibly a longer term increase due to dissolved lead. However, analysis of the lead measurements (below) showed that the increase was in fact largely due to dissolved lead, indicating that a transient peak in particulate material may have been missed by the sampling regime and/or there was an effect related to feed water quality.

The increase in lead concentration on Day 15 was found to correspond with a period of relatively high water temperature (22°C), coupled with relatively low phosphate and chlorine concentration (Figure 2.1 and Figure 2.2). During this period, the total lead concentrations from the test pipes increased from 8.2-12.3 µg/l to 16.9-22.9 µg/l (a mean increase of 10.1 µg/l); dissolved lead increased from 5.5-7.7 µg/l to 14.0-19.6 µg/l (a mean increase of 9.9 µg/l). Approximately 98% of the increase in total lead was attributed to dissolved lead. Lead concentrations from the control pipe increased similarly: total lead from 8.3 µg/l to 19.1 µg/l (a mean increase of 10.8 µg/l) and dissolved lead from 3.1 µg/l to 16.0 µg/l (a mean increase of 12.9 µg/l).

It is possible that this combination of conditions, particularly the short-term decrease in phosphate concentration (2.0 to 1.0 mg$PO_4$/l as P), resulted in the increase in dissolved lead concentrations seen at the time, as indicated by the simultaneous increase in dissolved lead for the control pipes.

## Particle counts for ‘hard water’ pipes

Prior to the installation of the water meters, particle counts in 30-MS samples from the test pipes measured 236-327 counts/ml in the 2-<5 µm range and 35-52 counts/ml in the 5-<10 µm range, and were comparable to counts in the feed water (267 counts/ml (2-<5 µm) and 57 counts/ml (5-<10 µm)). Counts from the control pipe were higher at 498 counts/ml (2-<5 µm) and 81 counts/ml (5-<10 µm).

[3] Observed on 2 August 2013.

Following the installation of water meters, all the test pipes showed an increase in particle counts in 30-MS samples, with initially a large variation in the measurements from the different pipes (see Figure 2.5). Initial particle counts from the test pipes showed increases up to 1675 counts/ml (2-<5 µm) and 419 counts/ml (5-<10 µm). Particle counts generally decreased in subsequent samples, and after the passage of about 172 litres of water counts were generally comparable to pre-installation values, up to 498 counts/ml (2-<5 µm) and 99 counts/ml (5-<10 µm).

Surprisingly, the largest increase in particle counts was observed for the control pipe, with counts increasing up to 2456 counts/ml (2-<5 µm) and 604 counts/ml (5-<10 µm) immediately following installation. As was observed for the test pipes, particle counts decreased substantially, to values more comparable to pre-installation, after the passage of 172 litres of water.

## Lead concentration from 'soft water' pipes

Pre-installation: Prior to the installation of the water meters, total and dissolved lead concentrations in 30-MS samples from the test pipes measured 2.3-3.2 µg/l and 1.5-2.1 µg/l, respectively; total and dissolved lead concentrations in the control pipe measured 2.1 µg/l and 1.7 µg/l, respectively.

Immediately following installation: Immediately following installation, total and dissolved lead concentrations in 1-litre flush samples from the test pipes measured 67.9-262 µg/l and 4.3-7.1 µg/l, respectively. The samples from the test pipes contained a large proportion of particulate lead (63.6-257.7 µg/l, 94-98% of the total lead) as a result of the installation procedure. Although the control pipe was not exposed to the vibration caused by the breaker, the sample also showed a large proportion of particulate lead (114.4 µg/l, 98%) as a result of the disturbance in temporarily relocating the pipe.

Total lead concentrations in 1-litre flush samples taken from the test pipes after the passage of 3.4 litres of water reduced to 7.1-37.7 µg/l (particulate lead 4.8-35.7 µg/l). The total lead concentration in the comparable sample from the control pipe measured 9.3 µg/l (particulate lead 7.6 µg/l). These values indicate the potential for reducing lead concentrations significantly as a result of flushing immediately following water meter installation.

The total and dissolved lead concentrations in the 30-MS samples taken from the test pipes immediately following installation increased to 14.8-419 µg/l and 2.8-3.8 µg/l, respectively, with the total lead concentrations substantially greater than the pre-installation values. The comparable values from the control pipe also increased substantially, to 109 µg/l and 3.0 µg/l, respectively. The increase in the total lead concentration was largely due to particulate material, 12.0-416 µg/l (81-99% of the total lead concentration) from the test pipes and 106 µg/l (97%) from the control pipe.

The concentration of particulate lead in the 30-MS samples decreased with the passage of water. Concentrations from the test and control pipes reduced to 7.6-78.1 µg/l and 33.8 µg/l, respectively, following the passage of 3.4 litres of water. The dissolved lead concentrations were largely unaffected by the passage of water, with the values from the test pipes (3.4-4.9 µg/l) comparable to that of the control pipe (3.2 µg/l).

Post-installation: The total and dissolved lead concentrations in the 30-MS samples from test Pipe 8 returned to approximate pre-installation values after 3 days following the passage of 3,471 pipe volumes of water (892 litres). A similar observation was made for the lead concentrations from the control pipe. Although dissolved lead concentrations from test Pipes 6 and 7 (1.9-2.2 µg/l) returned to approximate pre-installation values within 8 days, total lead concentrations generally remained higher than the pre-installation values until the end of the trial.

As observed for the hard water samples, although to a lesser extent, there was an increase in effluent lead concentrations after Day 15 from the soft water pipes, coinciding with a period of relatively high water temperature (24°C), coupled with relatively low chlorine concentration (total chlorine 0.07-0.08 mg/l). Phosphate concentration was also slightly lower than typical, reducing from 1.9 to 1.7 mg/l $PO_4$ as P).

During this period, the total lead concentration from test Pipe 8 increased from 2.4 µg/l to 14.7 µg/l; dissolved lead increased less substantially from 1.3 µg/l to 1.9 µg/l. Dissolved lead also increased for test Pipes 6 and 7, from 1.9-2.2 µg/l to 2.3-3.3 µg/l (a mean increase of 0.75 µg/l). Only the dissolved lead increased for the control pipe, from 1.2 µg/l to 1.8 µg/l.

As discussed for the hard water trial, it is possible that the combination of conditions contributed to the increase in the dissolved lead concentrations seen at this time. However, the magnitude of the increase in particulate lead from Pipe 8 (an outer pipe) suggests that this may also have been affected by a physical disturbance.

## Particle counts from ‘soft water’ pipes

Prior to the installation of the water meters, particle counts in 30-MS samples from the test pipes measured 605-760 counts/ml in the 2-<5 µm range and 118-132 counts/ml in the 5-<10µm range. Counts in the control pipe measured 789 counts/ml (2-<5 µm) and 154 counts/ml (5-<10 µm).

All of the test pipes showed an initial increase in particle counts in 30-MS samples following the installation of water meters (see Figure 2.8). Initial counts immediately after installation showed increases up to 3300 counts/ml (2-<5 µm) and 952 counts/ml (5-<10 µm). Particle counts generally decreased in subsequent samples and after the passage of about 172 litres of water counts were comparable to pre-installation values, up to 999 counts/ml (2-<5 µm) and 321 counts/ml (5-<10 µm).

As observed for the hard water, the largest increase in particle counts was observed for the control pipe, with counts increasing up to 4866 counts/ml (2-<5 µm) and 1546 counts/ml (5-<10 µm) immediately following installation. As was observed for the test pipes, particle counts decreased substantially after the passage of 172 litres of water to values more comparable to pre-installation.

### 2.3.5 Trial 1 Conclusions

The principal conclusions from the first trial:

- Lead concentrations in 1-litre flush and 30-MS samples increased substantially above the 10 µg/l standard following the installation of water meters into lead pipes on both hard and soft water supplies.

- Substantial increases in total lead concentrations immediately following installation of the water meters were largely due to particulate material arising from disturbance during the installation procedure including simulation of the use of a low-vibration breaker. However, total lead concentrations also increased substantially in the control pipes due to disturbance when temporarily relocating the pipes.

- Passage of approximately 13 pipe volumes of water (3.4 litres) through the test pipes reduced the mean total lead concentrations in 1-litre flush samples by up to 91%, although the 10 µg/l standard was still exceeded in four out of six samples.

- Total and dissolved lead concentrations in the 30-MS samples reduced to approximate pre-installation values after the passage of 3471 – 10479 pipe volumes of water (892-2,693 litres), after 3-8 days of operation.

- An observed increase in total and dissolved lead concentrations 15 days after the installation of the water meters may have been caused by a combination of changes in the feed water conditions (temperature, chlorine, phosphate) and/or a possible physical disturbance to the lead pipe rig.

## 2.4 Trial 2 - Simulation of 'low disturbance' installation of a water meter

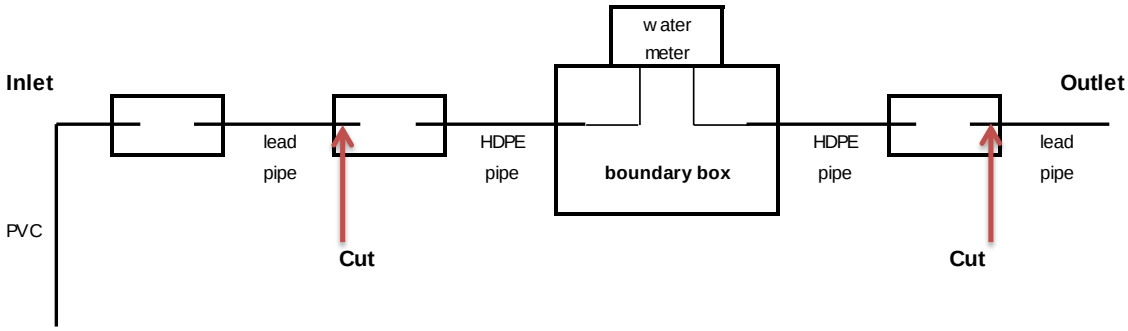
Following the installation of the water meters on 18 July 2013 and the subsequent stabilisation of effluent lead concentrations from the pipe rig, new boundary boxes and water meters were installed in Pipes 1, 2 and 3 (fed with hard water) and Pipes 6, 7 and 8 (fed with soft water) on 15 October 2013. Water meters were not installed to the remaining 2 pipes (Pipes 4 and 5), to act as the control pipes for the hard and soft waters, respectively.

In contrast to the first trial, the installation procedure was designed to minimise any physical disturbance to the lead pipes.

### 2.4.1 Preparation of Rig

The existing (old) boundary boxes/water meters were carefully removed from the lead pipes as indicated below.

**Figure 2.9 Pipe rig - Schematic diagram to show removal of boundary boxes and pipes**




A section of approximately 25 mm length was cut from the lead pipes on the inlet and outlet sides of the old boundary boxes, revealing a fresh lead surface. The lead pipe was cut with low compression pipe shears to minimise deformation of the pipe and the creation of particulate lead.

The new boundary boxes/water meters were installed in the gap left by the removal of the old equipment. The fresh lead surface of the cut pipe was left fully exposed to water.

New sections of blue HDPE pipe, each lengthened by approximately 2.5 cm, were installed either side of the boundary box.

Installation of the water meters reduced the length of lead pipe from 2.70 m to approximately 2.65 m (volume approximately 252 ml).

The control pipes remained in place and undisturbed throughout the installation procedure.

The rig was operated as previously and samples of effluent taken for lead analysis and particle counts.

### 2.4.2 Sampling and Analysis

The procedures for sampling and analysis were generally as for Trial 1 (Section 2.3). However, to ensure that effluent samples contained water that had been in contact with the freshly cut lead pipe at the inlet side of the boundary box, the 30-MS sample volume from test

Pipes 1, 2, 3, 6, 7 and 8 was increased to approximately 500 ml (490-530 ml), necessarily including water from the HDPE pipe/boundary box/water meter (230-240 ml).

The 30-MS samples from the test pipes thus contained water from the HDPE pipe/boundary box/water meter which had not been in contact with lead pipe during the stagnation periods, effectively diluting the concentration of lead from the pipe. Accordingly, the results from Trial 2 cannot be compared directly to those from Trial 1[4]. Sample volumes from the control pipes (Pipes 4 and 5) remained unchanged at 220 ml.

### 2.4.3 Trial 2 Results

#### Pipe feed waters

Analyses of the hard and soft feed waters are shown in Figure 2.1 and Figure 2.2 (Section 2), respectively.

#### Pipe effluents

Effluent lead concentrations in samples taken from the hard water pipes are shown in Table 2.6 and in Figure 2.10 and Figure 2.11; corresponding particle counts are shown in Table 2.7 and Figure 2.12.

Effluent lead concentrations in samples taken from the soft water pipes are shown in Table 2.8 and in Figure 2.13 and Figure 2.14; corresponding particle counts are shown in Table 2.9 and in Figure 2.15.

[4] Effluent lead concentrations from Trial 2 have been adjusted to allow for the volume of water contained in the HDPE pipe/boundary box/water meters and the results are compared with those from Trial 1 in Section 3.

**Table 2.6 Trial 2 – Lead analyses for pipes with hard water**

| Sample (Date) | Sample type | Cum. flow[1] | P1[2] Total lead | P1[2] Diss. lead | P2[2] Total lead | P2[2] Diss. lead | P3[2] Total lead | P3[2] Diss. lead | P4(c)[3] Total lead | P4(c)[3] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-installation** | | | | | | | | | | |
| 1 (14/10) | 8-HS | - | 22.3 | 16.7 | 22.1 | 17.0 | 14.2 | 12.8 | 16.3 | 13.1 |
| 2 (14/10) | 30-MS | - | 5.9 | 5.4 | 5.9 | 4.5 | 4.4 | 3.6 | 8.2 | 3.1 |
| **Immediately following installation** | | | | | | | | | | |
| 3 (15/10) | 1-L flush | 1.0/1.0 | 49.0 | 10.8 | 64.8 | 11.5 | 124.0 | 10.7 | 13.1 | 8.9 |
| 4 (15/10) | 30-MS | 1.5/1.2 | 19.1 | 12.6 | 26.7 | 12.5 | 41.4 | 9.3 | 9.9 | 7.9 |
| 5 (15/10) | 1-L flush | 2.5/2.2 | 6.9 | 7.0 | 8.8 | 6.9 | 7.5 | 5.1 | 3.4 | 3.1 |
| 6 (15/10) | 30-MS | 3.0/2.4 | 29.1 | 9.8 | 20.2 | 10.6 | 14.4 | 8.3 | 12.3 | 7.6 |
| 7 (15/10) | 1-L flush | 4.0/3.4 | 8.6 | 5.7 | 10.4 | 6.1 | 52.8 | 5.1 | 6.7 | 3.6 |
| 8 (15/10) | 30-MS | 4.5/3.7 | 10.3 | 9.2 | 13.7 | 9.6 | 28.5 | 21.0 | 9.5 | 7.6 |
| **Post-installation** | | | | | | | | | | |
| 9 (16/10) | 8-HS | 64 | 18.3 | 14.6 | 21.9 | 15.6 | 39.1 | 13.3 | 22.5 | 12.1 |
| 10 (16/10) | 30-MS | 172 | 9.1 | 8.5 | 9.5 | 8.5 | 166.0 | 7.4 | 6.1 | 5.9 |
| 12 (18/10) | 30-MS | 892 | 5.4 | 5.1 | 5.9 | 5.1 | 4.6 | 4.0 | 4.7 | 4.3 |
| 13 (23/10) | 30-MS | 2,693 | 5.2 | 4.3 | 5.6 | 4.8 | 4.2 | 3.8 | 4.0 | 0.3 |
| 14 (30/10) | 30-MS | 5,213 | 5.0 | 3.7 | 5.1 | 4.4 | 4.1 | 3.6 | 4.9 | 4.1 |
| 15 (06/11) | 30-MS | 7,733 | 8.7 | 7.8 | 8.6 | 7.7 | 7.0 | 6.4 | 7.4 | 6.4 |

Notes:

1. Cumulative flow: Sample nos. 3-8 based on flows to test pipes (P1-P3) and to control pipe (P4(c)); sample nos. 9-15 based on flow to control pipe.
2. Pipes 1, 2 and 3: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml; sample volume = 490-500 ml (sample time = 5.5 s).
3. Pipe 4 (control): Pipe length = 3.0 m; pipe volume = 285 ml; sample volume = 220 ml (sample time = 2.5 s).

**Figure 2.10 Trial 2 – Pre- and post-installation 30-MS effluent lead concentrations (hard water, time basis)**

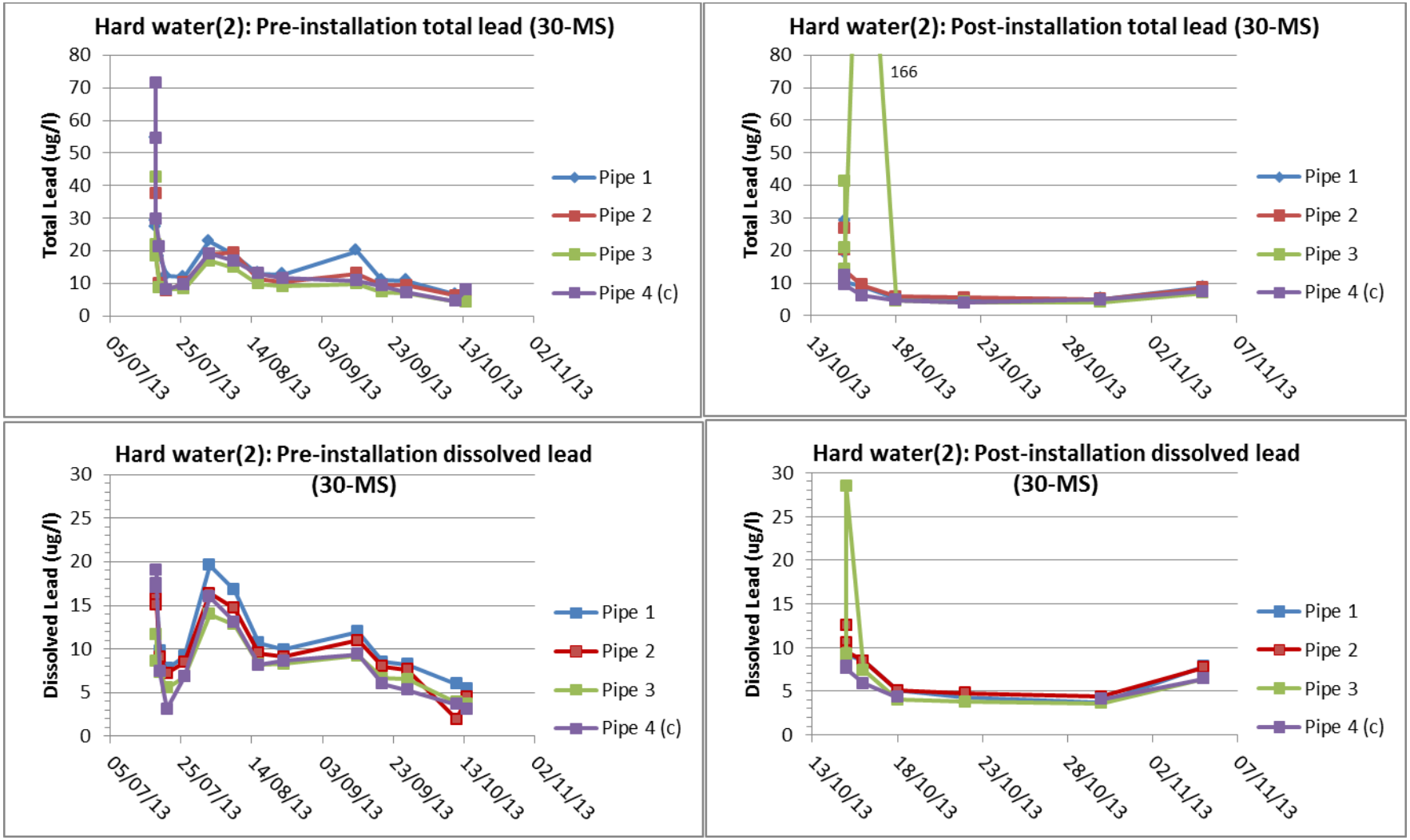


**Figure 2.11 Trial 2 – Pre- and post-installation 30-MS effluent lead concentrations (hard water, volume basis)**

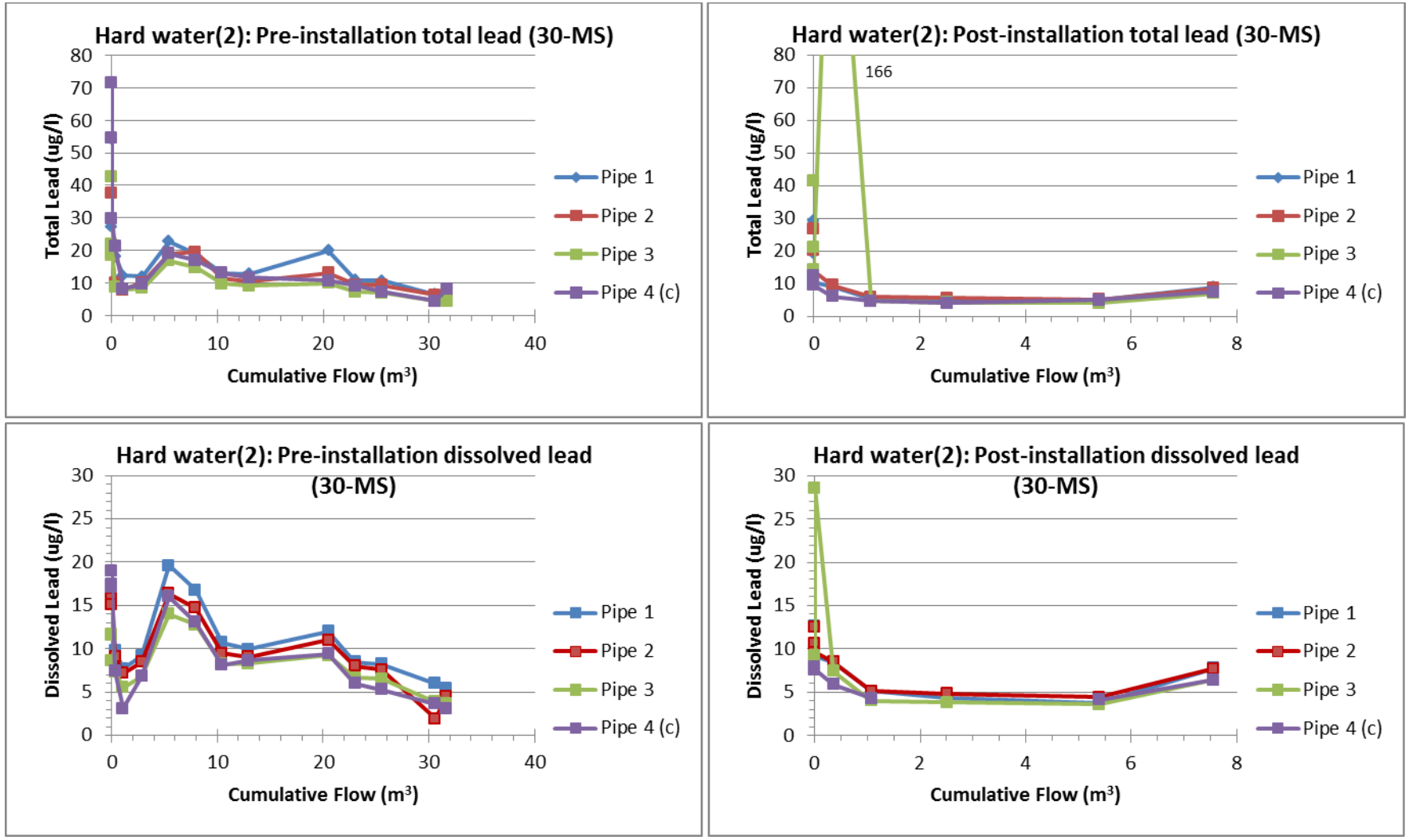


**Table 2.7 Trial 2 – Particle counts (hard water, counts/ml)**

| Sample (Date) | Sample type | Feed | | P1 | | P2 | | P3 | | P4(c) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm |
| **Pre-installation** | | | | | | | | | | | |
| 1 (14/10) | 8-HS | 28 | 4 | 179 | 45 | 301 | 49 | 168 | 39 | 489 | 60 |
| 2 (14/10) | 30-MS | 28 | 4 | 264 | 78 | 381 | 72 | 159 | 42 | 733 | 95 |
| **Immediately following installation** | | | | | | | | | | | |
| 3 (15/10) | 1-litre flush | 52 | 16 | 3120 | 763 | 4001 | 924 | 3986 | 1032 | 530 | 92 |
| 4 (15/10) | 30-MS | 52 | 16 | 783 | 160 | 1151 | 175 | 649 | 122 | 527 | 81 |
| 5 (15/10) | 1-litre flush | 52 | 16 | 747 | 133 | 642 | 112 | 476 | 94 | 458 | 90 |
| 6 (15/10) | 30-MS | 52 | 16 | 587 | 102 | 454 | 71 | 371 | 74 | 375 | 52 |
| 7 (15/10) | 1-litre flush | 52 | 16 | 402 | 73 | 404 | 76 | 302 | 68 | 293 | 51 |
| 8 (15/10) | 30-MS | 52 | 16 | 438 | 69 | 573 | 142 | 321 | 68 | 525 | 101 |
| **Post-installation** | | | | | | | | | | | |
| 9 (16/10) | 8-HS | 37 | 8 | 86 | 18 | 143 | 28 | 130 | 28 | 706 | 102 |
| 10 (16/10) | 30-MS | 37 | 8 | 182 | 25 | 185 | 27 | 166 | 21 | 652 | 76 |
| 12 (18/10) | 30-MS | 38 | 7 | 88 | 21 | 82 | 13 | 67 | 14 | 559 | 64 |
| 13 (23/10) | 30-MS | 53 | 12 | 123 | 25 | 98 | 17 | 104 | 22 | 810 | 123 |
| 14 (30/10) | 30-MS | 39 | 8 | 184 | 39 | 121 | 23 | 124 | 26 | 1517 | 175 |
| 15 (06/11) | 30-MS | 50 | 9 | 84 | 13 | 181 | 31 | 114 | 20 | 625 | 41 |

**Figure 2.12 Trial 2 – Feed and effluent particle counts (count/ml, pipes with hard water)**

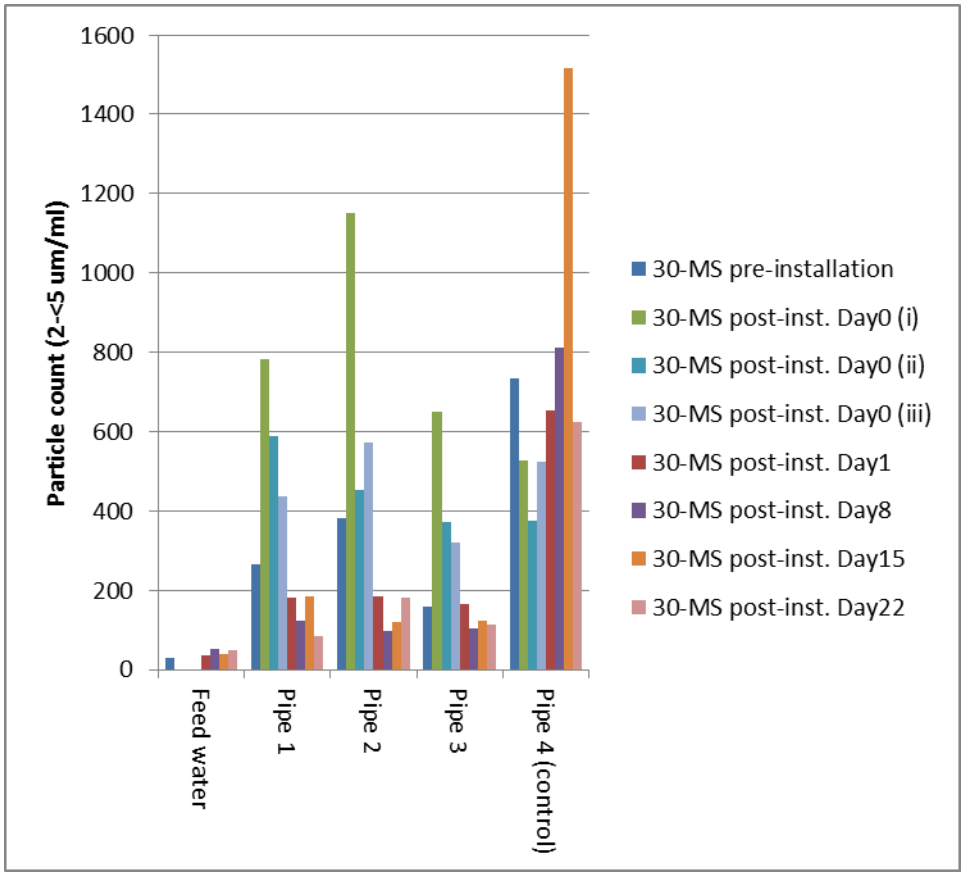


**Table 2.8 Trial 2 – Lead analyses for pipes with soft water**

| Sample (Date) | Sample type | Cum. flow[1] | P5(c)[2] Total lead | P5(c)[2] Diss. lead | P6[3] Total lead | P6[3] Diss. lead | P7[3] Total lead | P7[3] Diss. lead | P8[3] Total lead | P8[3] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-installation** | | | | | | | | | | |
| 1 (14/10) | 8-HS | - | 4.3 | 2.3 | 3.6 | 2.4 | 4.2 | 1.8 | 2.7 | 1.9 |
| 2 (14/10) | 30-MS | - | 1.1 | 0.9 | 1.2 | 0.5 | 1.4 | 0.8 | 1.0 | 0.8 |
| **Immediately following installation** | | | | | | | | | | |
| 3 (15/10) | 1-L flush | 1.0/1.0 | 2.6 | 1.2 | 51.7 | 2.8 | 278.0 | 2.6 | 41.4 | 2.5 |
| 4 (15/10) | 30-MS | 1.2/1.5 | 2.7 | 1.3 | 46.0 | 3.3 | 60.5 | 5.1 | 16.4 | 3.6 |
| 5 (15/10) | 1-L flush | 2.2/2.5 | 1.5 | 0.7 | 9.0 | 1.4 | 8.1 | 1.7 | 5.5 | 1.6 |
| 6 (15/10) | 30-MS | 2.4/3.0 | 2.3 | 1.1 | 23.2 | 2.0 | 14.8 | 1.9 | 4.0 | 1.3 |
| 7 (15/10) | 1-L flush | 3.4/4.0 | 2.4 | 0.7 | 18.8 | 1.5 | 8.6 | 1.2 | 2.3 | 1.0 |
| 8 (15/10) | 30-MS | 3.7/4.5 | 2.8 | 1.1 | 9.2 | 1.8 | 4.5 | 1.7 | 2.5 | 1.3 |
| **Post-installation** | | | | | | | | | | |
| 9 (16/10) | 8-HS | 64 | 3.2 | 2.5 | 12.1 | 3.4 | 10.2 | 2.6 | 5.8 | 2.4 |
| 10 (16/10) | 30-MS | 172 | 2.0 | 1.3 | 8.8 | 2.0 | 4.3 | 1.3 | 3.1 | 1.3 |
| 12 (18/10) | 30-MS | 892 | 1.1 | 0.8 | 1.1 | 0.5 | 2.1 | 0.9 | 0.9 | 0.7 |
| 13 (23/10) | 30-MS | 2,693 | 1.0 | 0.9 | 1.9 | 0.3 | 2.0 | 0.7 | 0.8 | 0.7 |
| 14 (30/10) | 30-MS | 5,213 | 2.0 | 1.0 | 3.1 | 1.0 | 2.5 | 0.9 | 1.0 | 0.8 |
| 15 (06/11) | 30-MS | 7,733 | 1.0 | 0.8 | 1.7 | 0.5 | 1.8 | 0.8 | 1.0 | 0.8 |

Notes:

1. Cumulative flow: Sample nos. 3-8 based on flows to control pipe (P5(c)) and to test pipes (P6-P8);sample nos. 9-15 based on flow to control pipe.
2. Pipe 5 (control): Pipe length = 3.0 m; pipe volume = 285 ml; sample volume = 220 ml (sample time = 2.5 s).
3. Pipes 6, 7 and 8: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml; sample volume = 490-530 ml (sample time = 5.5 s).

**Figure 2.13 Trial 2 – Pre- and post-installation 30-MS effluent lead concentrations (Soft water, time basis)**

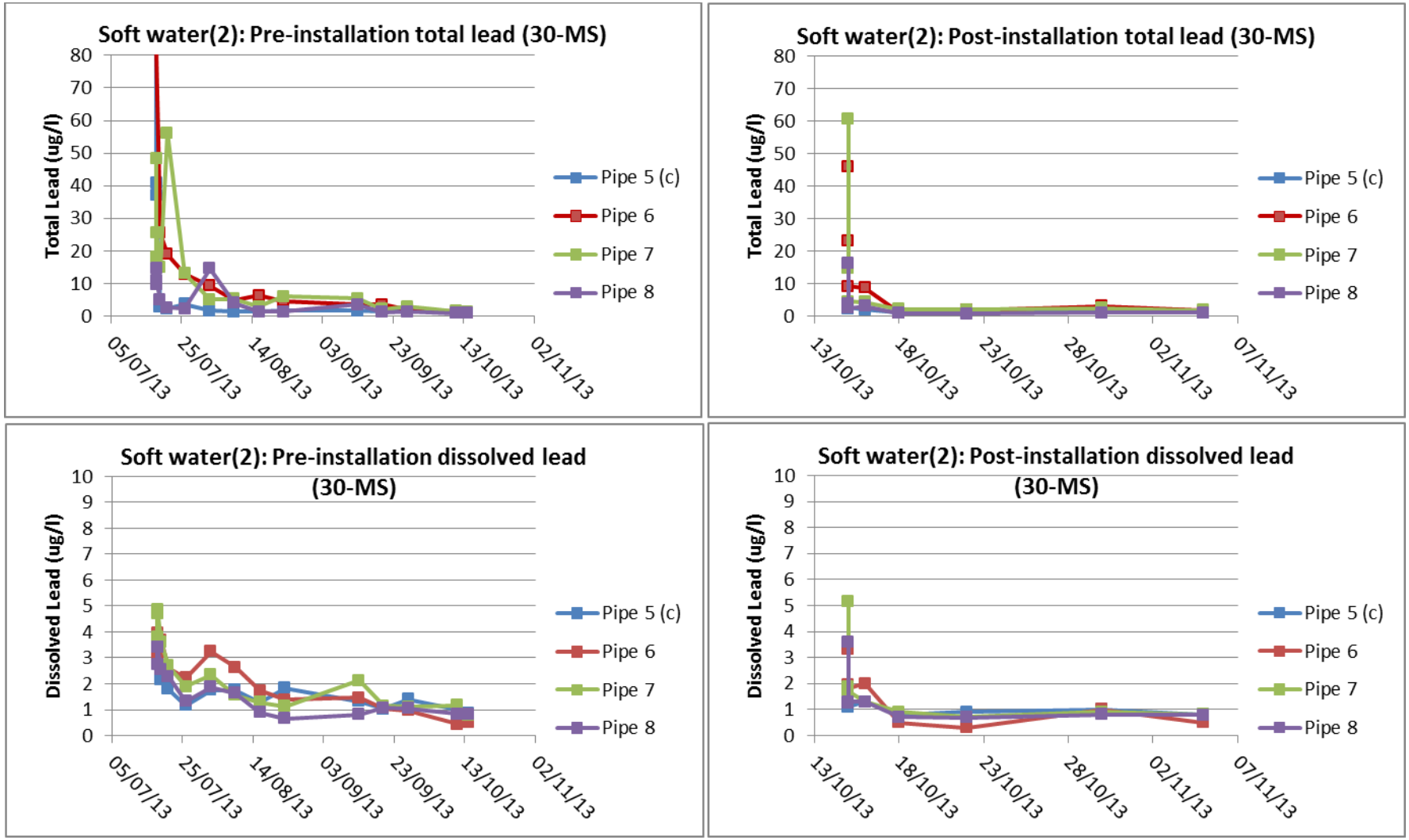


**Figure 2.14 Trial 2 – Pre- and post-installation 30-MS effluent lead concentrations (Soft water, volume basis)**

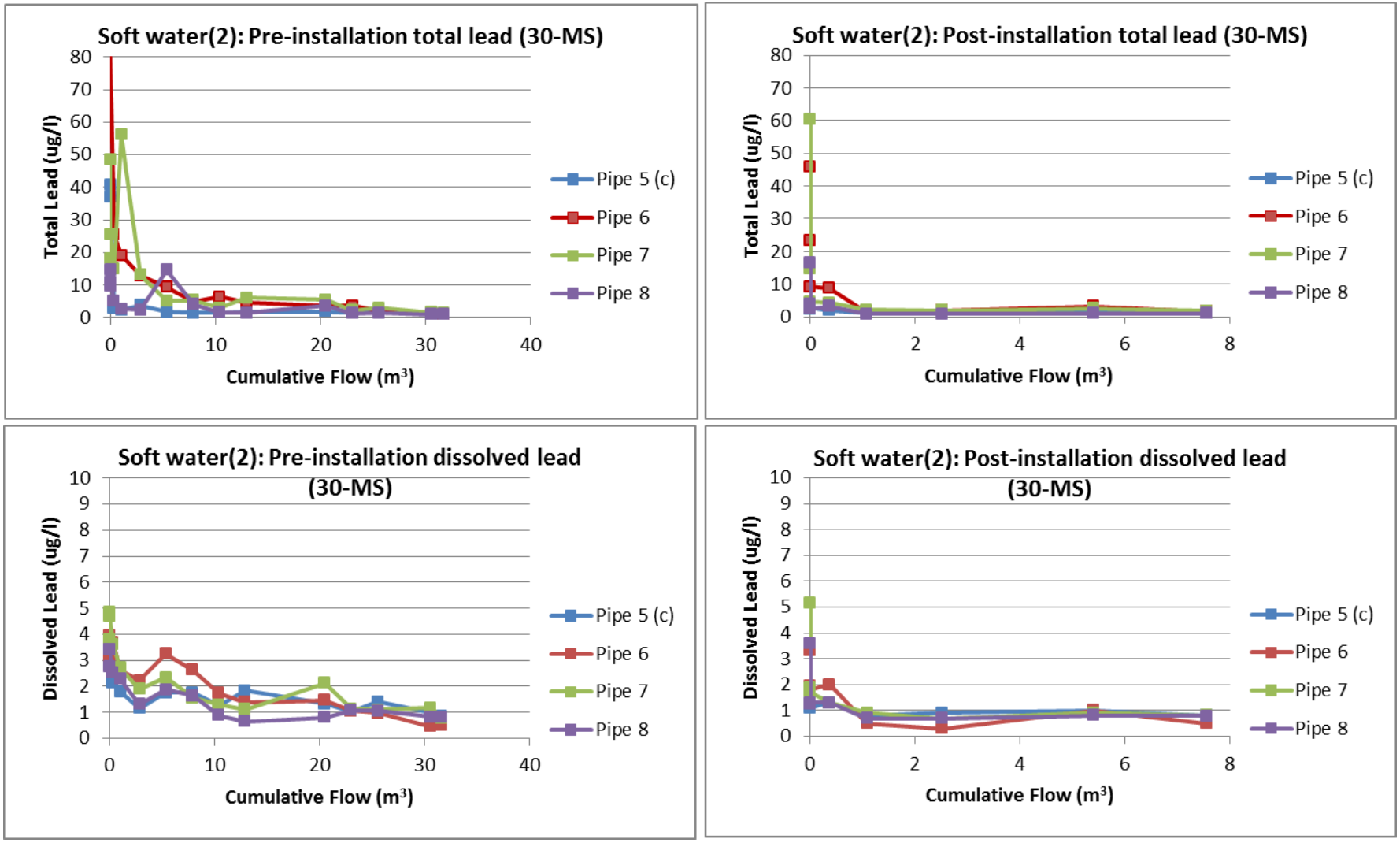
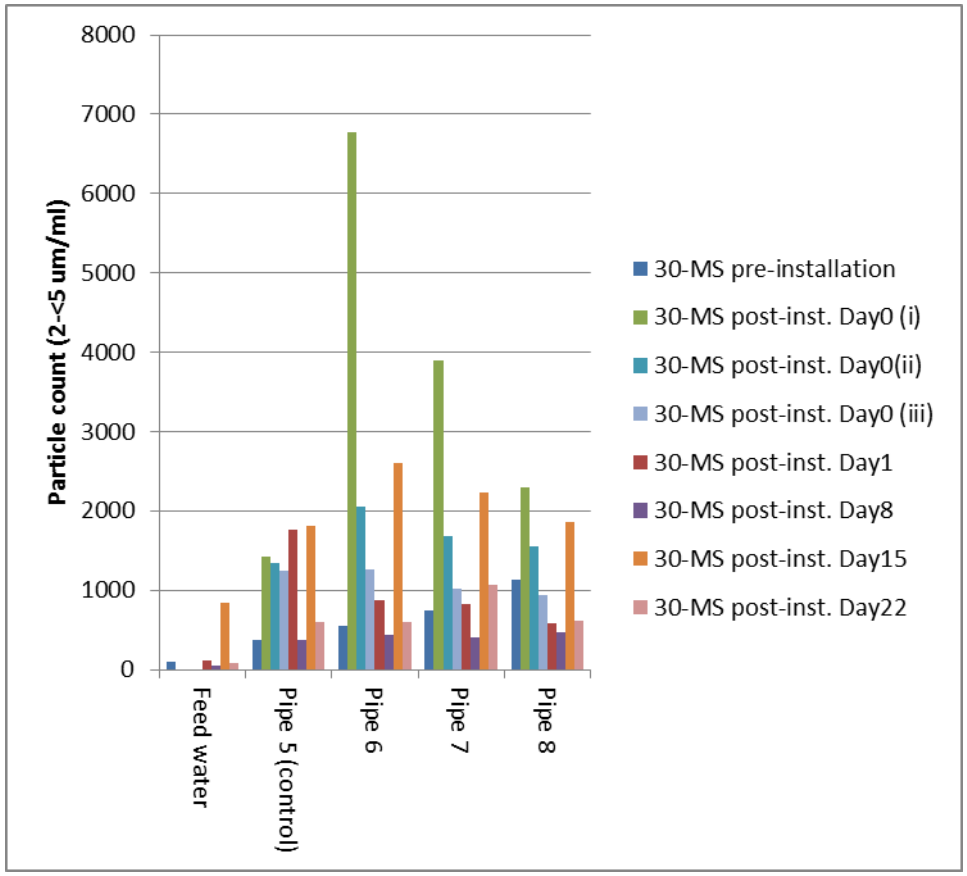


**Table 2.9 Trial 2 – Particle counts (Soft water, counts/ml)**

| Sample (Date) | Sample type | Feed | | P5(c) | | P6 | | P7 | | P8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm | 2-<5 µm | 5-<10 µm |
| **Pre-installation** | | | | | | | | | | | |
| 1 (14/10) | 8-HS | 102 | 18 | 300 | 103 | 406 | 108 | 511 | 109 | 564 | 123 |
| 2 (14/10) | 30-MS | 102 | 18 | 367 | 102 | 550 | 130 | 747 | 164 | 1139 | 208 |
| **Immediately following installation** | | | | | | | | | | | |
| 3 (15/10) | 1-litre flush | 92 | 23 | 2393 | 730 | 17512 | 7800 | 13539 | 5372 | 12021 | 4356 |
| 4 (15/10) | 30-MS | 92 | 23 | 1417 | 362 | 6773 | 2841 | 3896 | 1253 | 2299 | 690 |
| 5 (15/10) | 1-litre flush | 92 | 23 | 3805 | 1421 | 4748 | 1700 | 3555 | 1280 | 3558 | 1323 |
| 6 (15/10) | 30-MS | 92 | 23 | 1334 | 402 | 2055 | 699 | 1686 | 495 | 1560 | 446 |
| 7 (15/10) | 1-litre flush | 92 | 23 | 1564 | 476 | 1904 | 613 | 1527 | 470 | 1394 | 422 |
| 8 (15/10) | 30-MS | 92 | 23 | 1244 | 339 | 1268 | 400 | 1018 | 328 | 933 | 296 |
| **Post-installation** | | | | | | | | | | | |
| 9 (16/10) | 8-HS | 107 | 21 | 404 | 121 | 620 | 177 | 507 | 119 | 687 | 123 |
| 10 (16/10) | 30-MS | 107 | 21 | 1761 | 373 | 878 | 185 | 821 | 163 | 575 | 117 |
| 12 (18/10) | 30-MS | 94 | 17 | 266 | 72 | 260 | 67 | 307 | 74 | 358 | 77 |
| 13 (23/10) | 30-MS | 46 | 10 | 364 | 109 | 443 | 119 | 405 | 101 | 462 | 131 |
| 14 (30/10) | 30-MS | 839 | 136 | 1818 | 311 | 2595 | 432 | 2225 | 352 | 1862 | 263 |
| 15 (06/11) | 30-MS | 83 | 16 | 606 | 100 | 604 | 122 | 1066 | 193 | 610 | 127 |

**Figure 2.15 Trial 2 – Particle counts (Soft water, 2-<5 µm, count/ml)**



### 2.4.4 Trial 2 Discussion

#### Lead concentration from 'hard water' pipes

Pre-installation: Following the completion of Trial 1 and immediately prior to the installation of the new water meters, total and dissolved lead concentrations in 30-MS samples from the test pipes measured 4.4-5.9 µg/l and 3.6-5.4 µg/l, respectively. Lead concentrations in comparable samples from the control pipe measured 8.2 µg/l and 3.1 µg/l, respectively.

Immediately following installation: Immediately following installation, total and dissolved lead concentrations in 1-litre flush samples from the test pipes measured 49.0-124 µg/l and 10.7-11.5 µg/l, respectively. The samples contained a large proportion of particulate lead (38.2-113.3 µg/l (78-91% of the total lead concentration)). Comparable samples from the control pipe contained significantly smaller concentrations of total and dissolved lead, measuring 13.1 µg/l and 8.9 µg/l, respectively, with particulate lead calculated as 4.2 µg/l (32%).

*The lead concentrations from the test pipes were comparable to those measured in Trial 1 (total lead: 19.6-106 µg/l; dissolved lead: 4.7-6.5 µg/l; particulate lead 13.1-101.3 µg/l), even though the samples were 'diluted' by the sampling procedure and the installation procedure had minimised any physical disturbance.*

Total and dissolved lead concentrations in 1-litre flush samples taken from the test pipes after the passage of about 4.0 litres of water reduced to 8.6-52.8 µg/l and 5.1-6.1 µg/l, respectively, with particulate lead calculated as 2.9-47.7 µg/l. The comparable samples from the control pipe measured 6.7 µg/l and 3.6 µg/l, respectively, with particulate lead 3.1 µg/l. These values indicate the potential for reducing lead concentrations significantly as a result of flushing immediately following water meter installation.

The total and dissolved lead concentrations in the 30-MS samples taken from the test pipes immediately following installation increased to 19.1-41.4 µg/l and 9.3-12.6 µg/l, respectively, substantially greater than the pre-installation values. The comparable values from the control pipe also increased, to 9.9 µg/l and 7.9 µg/l, respectively. The increase in the total lead concentration from the test pipes was due largely to particulate material, 6.5-32.1 µg/l, whereas the increase from the control pipe was due largely to dissolved lead.

The concentration of particulate lead in the 30-MS samples from the test pipes decreased with the passage of water to 1.1-7.5 µg/l following the passage of 4.5 litres of water, whilst the concentration of particulate lead from the control pipe was largely unchanged at 1.9 µg/l. The dissolved lead concentrations were largely unaffected by the passage of water and remained relatively high, with the values from the test pipes (9.2-21.0 µg/l) higher than that of the control pipe (7.6 µg/l).

*Although the latter observation with regard to the dissolved lead concentration might suggest an effect caused by dissolution from the freshly cut lead surface, a similar observation was made in Trial 1 when the 30-MS samples were not in contact with the cut lead surface.*

Post-installation: The total and dissolved lead concentrations in the 30-MS samples from the test pipes and the control pipe approached pre-installation values within 3 days of operation, after the passage of up to 890 litres of water.

## Particle counts for 'hard water' pipes

Prior to the installation of the water meters for Trial 2, particle counts in 30-MS samples from the test pipes measured 159-381 counts/ml in the 2-<5 µm range and 42-78 counts/ml in the 5-<10 µm range, higher than counts in the feed water (28 counts/ml (2-<5 µm) and 4 counts/ml (5-<10 µm)). Counts from the control pipe were higher still, measuring 733 counts/ml (2-<5 µm) and 95 counts/ml (5-<10 µm).

Following the installation of the water meters, all the test pipes showed an initial increase in particle counts in 30-MS samples (see Figure 2.11). Initial counts from the test pipes immediately after the installation showed increases up to 1151 counts/ml (2-<5 µm) and 175 counts/ml (5-<10 µm). Particle counts generally decreased in subsequent samples, and after the passage of about 172 litres of water counts were lower than pre-installation values, measuring up to 185 counts/ml (2-<5 µm) and 27 counts/ml (5-<10 µm).

Particle counts measured for the control pipe were generally unaffected by the installation procedure, measuring 527 counts/ml (2-<5 um) and 81 counts/ml (5-<10 um) in samples taken immediately after the installation, and 652 counts/ml (2-<5 um) and 76 counts/ml (5-<10 um) after the passage of 172 litres of water.

## Lead concentration from 'soft water' pipes

Pre-installation: Prior to the installation of the water meters, total and dissolved lead concentrations in 30-MS samples from the test pipes measured 1.0-1.4 µg/l and 0.5-0.8 µg/l, respectively; total and dissolved lead concentrations in the control pipe measured 1.1 µg/l and 0.9 µg/l, respectively.

Immediately following installation: Immediately following installation, total and dissolved lead concentrations in 1-litre flush samples from the test pipes measured 41.4-278 µg/l and 2.5-2.8 µg/l, respectively. The samples from the test pipes contained a large proportion of particulate lead (38.9-275 µg/l (94-99%)). Comparable samples from the control pipe contained significantly smaller concentrations of total and dissolved lead, measuring 2.6 µg/l and 1.2 µg/l, respectively, with particulate lead calculated as 1.4 µg/l (54%).

*The increased lead concentrations from the test pipes were comparable to those seen in Trial 1 (total lead: 67.9-262 µg/l; dissolved lead: 4.3-7.1 µg/l; particulate lead 63.6-258 µg/l), even*

*though the samples were 'diluted' by the sampling procedure and the installation procedure had minimised any physical disturbance.*

Total and dissolved lead concentrations in 1-litre flush samples taken from the test pipes after the passage of about 3.4 litres of water reduced to 2.3-18.8 µg/l and 1.0-1.5 µg/l, respectively, with particulate lead calculated as 1.3-17.3 µg/l. The comparable samples from the control pipe contained 2.4 µg/l and 0.7 µg/l, respectively, with particulate lead calculated as 1.7 µg/l. These values indicate the potential for reducing lead concentrations significantly as a result of flushing immediately following water meter installation.

The total and dissolved lead concentrations in the 30-MS samples taken from the test pipes immediately following installation measured 16.4-60.5 µg/l and 3.3-5.1 µg/l, respectively, substantially greater than the pre-installation values. The comparable values from the control pipe also increased, to 2.7 µg/l and 1.3 µg/l, respectively. The increase in the total lead concentration was largely due to particulate material, 12.8-55.4 µg/l (78-93% of the total lead concentration) from the test pipes and 1.4 µg/l (52%) from the control pipe.

The concentration of particulate lead in the 30-MS samples from the test pipes decreased with the passage of water to 1.2-7.4 µg/l following the passage of 4.5 litres of water, whilst the concentration of particulate lead from the control pipe was effectively unchanged at 1.7 µg/l. The dissolved lead concentrations from the test pipes decreased (1.3-1.8 µg/l) whilst the concentration from the control pipe was effectively unchanged (1.1 µg/l).

Post-installation: The total and dissolved lead concentrations in the 30-MS samples from the test pipes (0.9-2.1 µg/l; 0.5-0.9 µg/l) and the control pipe (1.1 µg/l; 0.8 µg/l) approached approximate pre-installation values after the passage of about 890 litres of water, after 3 days operation.

## Particle counts for 'soft water' pipes

Prior to the installation of the water meters for Trial 2, particle counts in 30-MS samples from the test pipes measured 550-1139 counts/ml in the 2-<5 µm range and 130-208 counts/ml in the 5-<10 µm range, greater than counts in the feed water (102 counts/ml (2-<5 µm) and 18 counts/ml (5-<10 µm)). Counts from the control pipe measured 367 counts/ml (2-<5 µm) and 102 counts/ml (5-<10 µm).

Following the installation of water meters, particle counts from the test pipes and the control pipe increased substantially. The presence of 'floc-like' particulate was also visible in the samples. However, after the passage of about 172 litres of water, counts from the test pipes were comparable to pre-installation values, 575-878 counts/ml (2->5 µm) and 117-185 counts/ml (5-<10 µm). Counts from the control pipe were comparable to pre-installation values after the passage of 892 litres of water, after 3 days operation.

## 2.5 Trial 3 – Simulation of in-pipe air/water turbulence

The results of Trials 1 ('high disturbance') and 2 ('low disturbance') showed high lead concentrations in the test pipe effluents immediately following the installation of the water meters, but also in the control pipes for Trial 1 (when the control pipes were temporarily relocated and therefore unaffected by the disturbance during installation). One factor that was common to the above was that the lead pipes partially drained during installation/relocation.

The lead concentrations in the control pipe effluents for Trial 2 were relatively unchanged following the installation of the water meters into the test pipes. The control pipes remained *in-situ* during the installation and did not drain.

From these observations it is hypothesised that air/water turbulence during the pipe refilling phase can physically degrade the protective lead phosphate layer and contribute to the effluent lead concentrations, initially through increased particulate lead and then through increased dissolved lead whilst the protective layer recovers.

Trial 3 aimed to:

- investigate and elucidate the effect of air/water turbulence on lead pipes and effluent lead concentrations;
- inform procedures for the subsequent field trials;
- provide evidence for any subsequent guidance to the water industry.

### 2.5.1 Trial 2 Conclusions

The principal conclusions from the second trial:

- Lead concentrations in 1-litre flush and 30-MS samples increased substantially above the 10 µg/l standard following the installation of water meters into lead pipes on both hard and soft water supplies.
- Substantial increases in total lead concentrations immediately following installation of the water meters were largely due to particulate material, although the installation procedure was designed to minimise any disturbance.
- Total lead concentrations in 30-MS samples from the control pipes were not appreciably increased as a result of the minimal disturbance created by the water meter installation procedure.

- Passage of 3.4-4.0 litres of water through the test pipes reduced mean total lead concentrations in 1-litre flush samples by up to 92%, although the 10 µg/l standard was still exceeded in three out of six samples.

- Total and dissolved lead concentrations in the 30-MS samples reduced to approximate pre-installation values (4.4-5.9 µg/l and 3.6-5.4 µg/l, respectively µg/l) after the passage of 892 litres of water, after 3 days operation.

### 2.5.2 Methodology

#### Test pipes

The methodology, whilst elucidating the previous observations outlined above, was also designed to simulate installation procedures in the field:

- partial drainage of the customer's lead supply pipe when cut;

The rotameter valves on the test pipes were closed and the pipes isolated from the feed water supply. The water meters were carefully removed to allow drainage of the test pipes/boundary boxes. The total volume of water drained from each pipe measured 425-435 ml; the volume of water drained during the tests measured 290-300 ml, about 69% of the total. The water meters were then carefully re-installed.

- initial pressurisation of the supply pipe when reconnected to the mains (via the installed water meter);

The feed pumps were run up to operating pressure (1.3 bar) and the rotameter valves opened to allow the partially drained pipes to pressurise for 2 minutes.

- initial water flow through the supply pipe as the customer's (kitchen) tap is opened to release air/water to drain.

After the 2-minute pressurisation period, the sample valves were opened and samples taken at the pre-determined flow rates as indicated in Table 2.10.

**Table 2.10 Sampling regime for Trial 3 tests**

| Sample | Sample type | Flow rate (l/min) | | |
|---|---|---|---|---|
| | | Trial 3a | Trial 3b | Trial 3c |
| Day 0 (i) | 1-L flush | 1 | 6 | 12-15 |
| Day 0 (ii) | 30-MS | 1 | 6 | 12-15 |
| Day 0 (iii) | 1-L flush | 1 | 6 | 12-15 |
| Day 0 (iv) | 30-MS | 1 | 6 | 12-15 |
| Day 0 (v) | 1-L flush | 1 | 6 | 12-15 |
| Day 0 (vi) | 30-MS | 1 | 6 | 12-15 |
| Day 0 (vii) | 1-L flush | 6 | 6 | 6 |
| Day 1 | 30-MS | 6 | 6 | 6 |
| Day 3 | 30-MS | 6 | 6 | 6 |
| Day 8 | 30-MS | 6 | 6 | 6 |

Trial 3(a) was carried out between 19/03/14 (Day 0) to 27/03/14 (Day 8), Trial 3(b) was carried between 28/03/13-05/04/14, and Trial 3(c) was carried out between 03/06/14-11/06/14. The delay between Trials 3(b) and 3(c) was due to modifications made to the pipe rig to enable flushing at the higher rate. During this period, the rig was operated as normal at 6 l/min.

### Control pipes

The control pipes were operated and sampled as described for the test pipes but without partial drainage.

## 2.5.3 Trial 3(a) – Low rate (1 l/min) refill

Trial 3(a) was carried out to investigate refilling and flushing the test pipes at an initial low rate (1 l/min). After passage of about 4.75 l of water, equivalent to approximately 19 pipe volumes, the flow rate was increased to 6 l/min for the remainder of the trial (i.e. the flow rate maintained throughout Trials 1 and 2).

### Feed water analysis

Analyses of the hard and soft feed waters are shown in Figure 2.1 and Figure 2.2 respectively (Section 2.3.3).

## Pipe effluent analysis

Effluent lead concentrations taken from the hard and soft water pipes are shown in Table 2.11 and Table 2.12 respectively, and in Figure 2.16.

**Table 2.11 Trial 3(a) Low air/water turbulence – Lead analyses for pipes with hard water**

| Sample | Sample type | Cumulative flow | P1[1] Total lead | P1[1] Diss. lead | P2[1] Total lead | P2[1] Diss. lead | P3[1] Total lead | P3[1] Diss. lead | P4(c)[2] Total lead | P4(c)[2] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-test** | | | | | | | | | | |
| Pre-test | 30-MS | - | 6.3 | 5.9 | 6.2 | 6.0 | 5.5 | 4.7 | 4.6 | 4.6 |
| **Post-test** | | | | | | | | | | |
| Day 0 (i) | 1-L flush | 1.0 | 6.8 | 3.7 | 15.9 | 3.8 | 5.7 | 2.8 | 3.6 | 3.7 |
| Day 0 (ii) | 30-MS | 1.25 | 23.4 | 9.5 | 14.4 | 10.2 | 8.9 | 7.7 | 6.0 | 5.5 |
| Day 0 (iii) | 1-L flush | 2.25 | 5.7 | 4.2 | 6.5 | 4.3 | 3.8 | 4.0 | 3.4 | 3.4 |
| Day 0 (iv) | 30-MS | 2.5 | 10.6 | 9.6 | 10.3 | 9.2 | 7.5 | 7.5 | 6.1 | 6.1 |
| Day 0 (v) | 1-L flush | 3.5 | 4.8 | 3.7 | 4.0 | 4.0 | 3.2 | 3.2 | 3.3 | 3.3 |
| Day 0 (vi) | 30-MS | 3.75 | 9.6 | 8.7 | 9.7 | 9.1 | 7.4 | 7.0 | 6.2 | 6.0 |
| Day 0 (vii) | 1-L flush | 4.75 | 5.0 | 5.0 | 5.2 | 4.8 | 4.3 | 3.9 | 4.2 | 4.0 |
| Day 1 | 30-MS | 293 | 6.9 | 6.5 | 7.6 | 6.4 | 5.0 | 5.3 | 4.5 | 4.5 |
| Day 3 | 30-MS | 1013 | 6.5 | 6.3 | 6.3 | 6.0 | 5.1 | 4.3 | 4.1 | 4.3 |
| Day 8 | 30-MS | 2813 | 6.9 | 6.0 | 7.3 | 6.3 | 5.0 | 4.9 | 4.9 | 5.0 |

Notes:

1. Pipes 1, 2 and 3: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml.
2. Pipe 4 (control): Pipe length = 3.0 m; pipe volume = 285 ml.

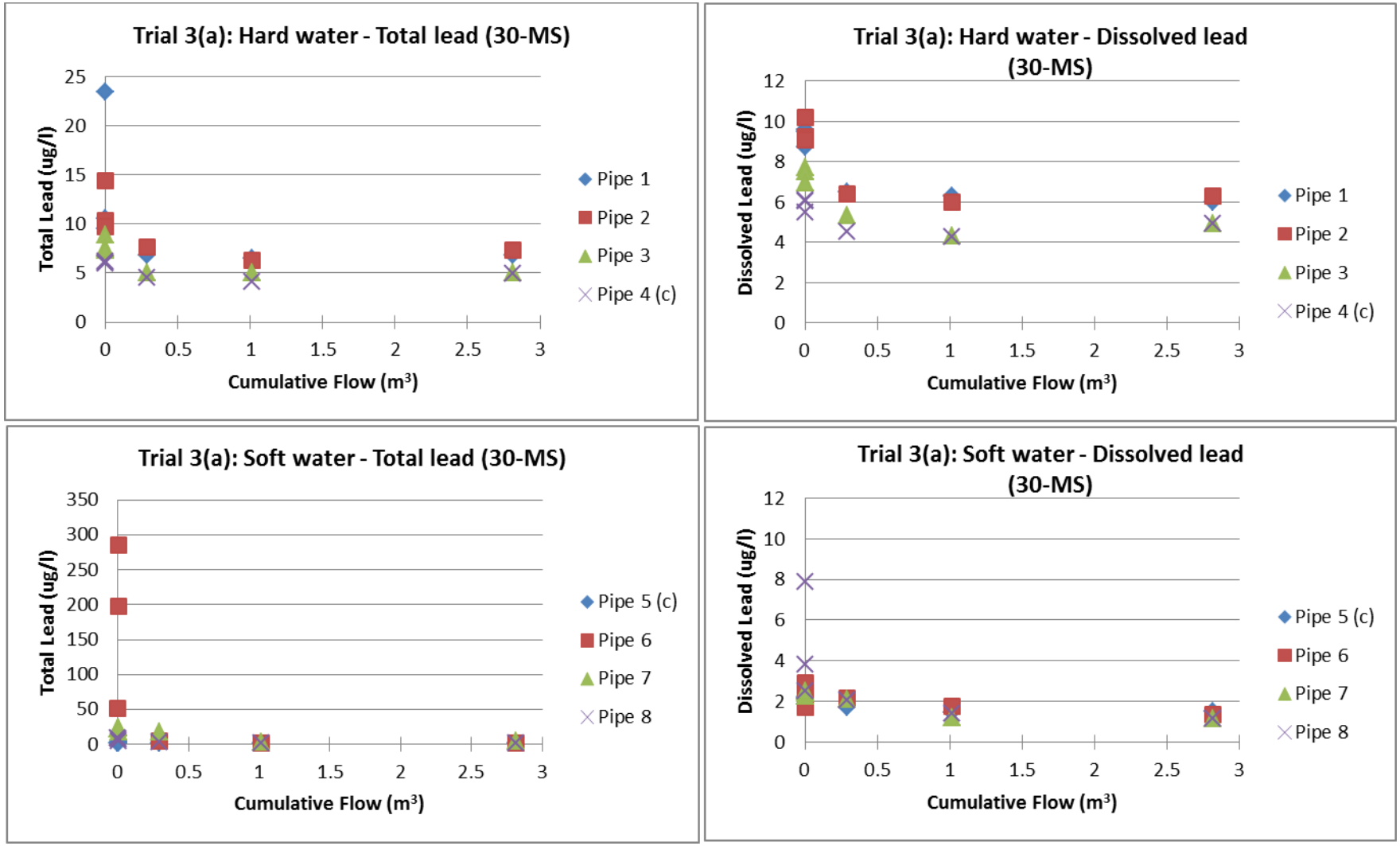
**Table 2.12 Trial 3(a) Low air/water turbulence – Lead analyses for pipes with soft water**

| Sample | Sample type | Cumulative flow | P5(c)[1] Total lead | P5(c)[1] Diss. lead | P6[2] Total lead | P6[2] Diss. lead | P7[2] Total lead | P7[2] Diss. lead | P8[2] Total lead | P8[2] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-test** | | | | | | | | | | |
| Pre-test | 30-MS | - | 2.1 | 1.8 | 2.9 | 2.2 | 3.8 | 1.7 | 2.3 | 1.9 |
| **Post-test** | | | | | | | | | | |
| Day 0 (i) | 1-L flush | 1.0 | 2.1 | 1.7 | 612 | 1.4 | 405 | 2.2 | 67.9 | 2.1 |
| Day 0 (ii) | 30-MS | 1.25 | 2.3 | 1.9 | 51.4 | 2.2 | 22.7 | 2.2 | 8.7 | 7.9 |
| Day 0 (iii) | 1-L flush | 2.25 | 1.9 | 1.9 | 3.5 | 1.4 | 14.1 | 1.8 | 2.1 | 2.1 |
| Day 0 (iv) | 30-MS | 2.5 | 2.5 | 2.1 | 286 | 2.9 | 17.3 | 2.4 | 7.2 | 3.8 |
| Day 0 (v) | 1-L flush | 3.5 | 1.6 | 1.6 | 1.4 | 1.4 | 5.0 | 1.4 | 1.3 | 1.2 |
| Day 0 (vi) | 30-MS | 3.75 | 2.2 | 2.2 | 198 | 1.7 | 23.2 | 2.5 | 4.3 | 2.5 |
| Day 0 (vii) | 1-L flush | 4.75 | 2.1 | 1.7 | 11.3 | 1.2 | 2.7 | 1.2 | 6.1 | 1.4 |
| Day 1 | 30-MS | 293 | 2.1 | 1.7 | 4.8 | 2.2 | 17.6 | 2.1 | 3.4 | 2.0 |
| Day 3 | 30-MS | 1013 | 1.4 | 1.4 | 1.7 | 1.7 | 3.4 | 1.2 | 1.9 | 1.4 |
| Day 8 | 30-MS | 2813 | 1.2 | 1.5 | 1.8 | 1.3 | 3.8 | 1.2 | 1.3 | 1.1 |

Notes:

1. Pipe 5 (control): Pipe length = 3.0 m; pipe volume = 285 ml.
2. Pipes 6, 7 and 8: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml.

**Figure 2.16 Trial 3(a) Low air/water turbulence – Effluent lead concentration (30-MS)**



### 2.5.4 Trial 3(b) – Medium rate (6 l/min) refill

Trial 3(b) was carried out to investigate refilling and flushing the test pipes at the rate (6 l/min) used throughout Trials 1 and 2.

#### Results

Analyses of the hard and soft feed waters are shown in Figures 2.1 and 2.2, respectively.

Effluent lead concentrations taken from the hard and soft water pipes are shown in Table 2.13 and Table 2.14 respectively, and in Figure 2.17.

**Table 2.13 Trial 3(b) Medium air/water turbulence – Lead analyses for pipes with hard water**

| Sample | Sample type | Cumulative flow | P1[1] Total lead | P1[1] Diss. lead | P2[1] Total lead | P2[1] Diss. lead | P3[1] Total lead | P3[1] Diss. lead | P4(c)[2] Total lead | P4(c)[2] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-test** | | | | | | | | | | |
| Pre-test | 30-MS | - | 6.9 | 6.0 | 7.3 | 6.3 | 5.0 | 4.9 | 4.9 | 5.0 |
| **Post-test** | | | | | | | | | | |
| Day 0 (i) | 1-L flush | 1.0 | 7.1 | 5.8 | 9.5 | 5.7 | 6.2 | 3.9 | 7.5 | 6.2 |
| Day 0 (ii) | 30-MS | 1.25 | 18.5 | 13.6 | 16.3 | 14.1 | 17.0 | 10.0 | 11.6 | 10.2 |
| Day 0 (iii) | 1-L flush | 2.25 | 6.7 | 6.2 | 7.3 | 6.9 | 5.6 | 4.8 | 5.3 | 5.0 |
| Day 0 (iv) | 30-MS | 2.5 | 14.1 | 11.0 | 13.8 | 12.4 | 9.2 | 8.4 | 9.6 | 9.9 |
| Day 0 (v) | 1-L flush | 3.5 | 8.8 | 8.1 | 9.1 | 8.4 | 66.2 | 6.2 | 6.5 | 6.8 |
| Day 0 (vi) | 30-MS | 3.75 | 13.2 | 11.9 | 14.3 | 12.7 | 9.5 | 9.1 | 10.1 | 9.4 |
| Day 0 (vii) | 1-L flush | 4.75 | 7.2 | 7.0 | 8.2 | 7.4 | 5.6 | 5.0 | 5.8 | 5.8 |
| Day 1 | 30-MS | 293 | 10.6 | 8.9 | 10.9 | 8.9 | 8.6 | 7.5 | 7.7 | 7.0 |
| Day 3 | 30-MS | 1013 | 7.5 | 5.5 | 6.2 | 5.6 | 5.4 | 4.6 | 4.6 | 4.3 |
| Day 8 | 30-MS | 2813 | 6.3 | 4.9 | 6.1 | 4.7 | 4.7 | 3.8 | 4.8 | 3.9 |

Notes:

1. Pipes 1, 2 and 3: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml.
2. Pipe 4 (control): Pipe length = 3.0 m; pipe volume = 285 ml.

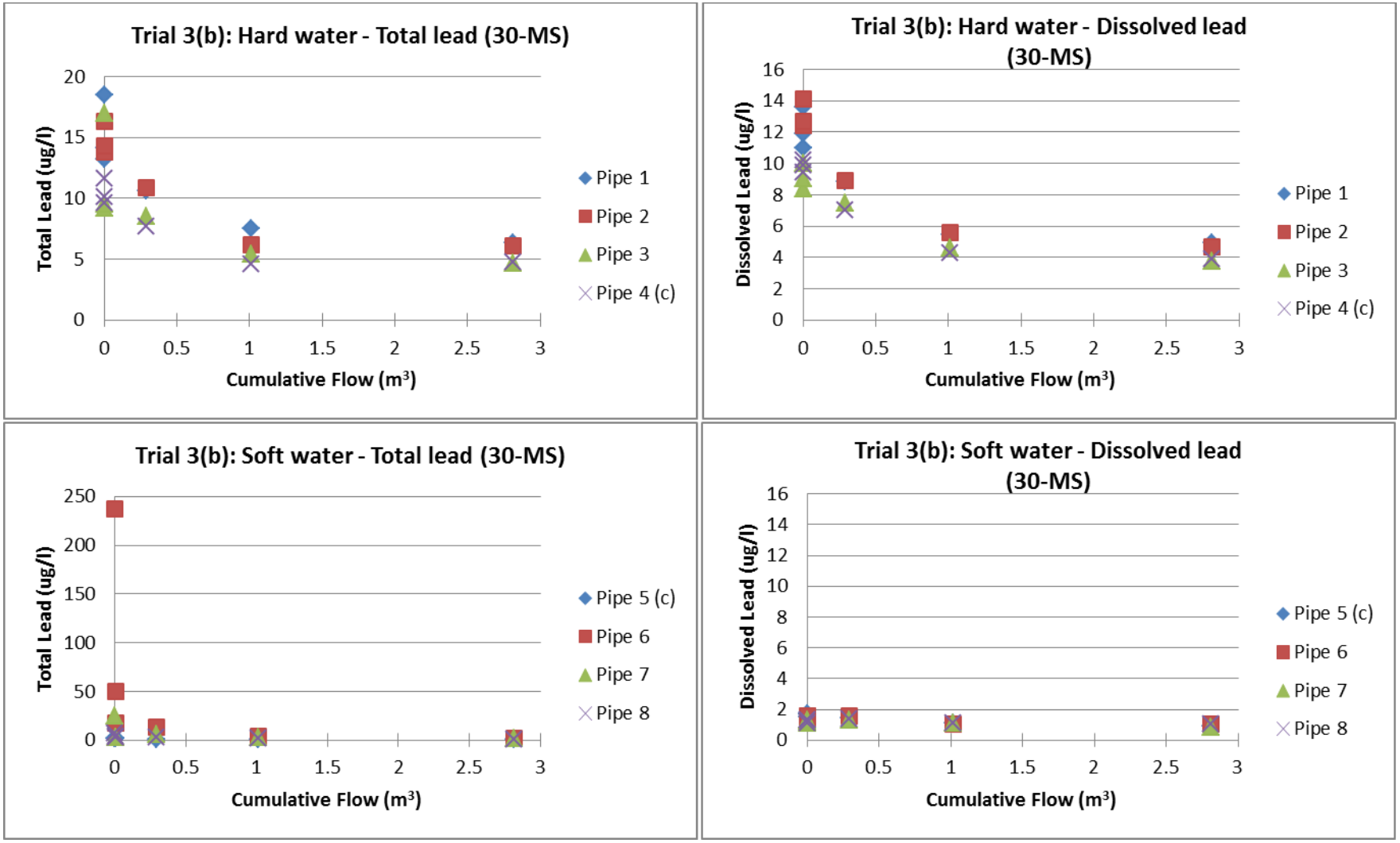
**Table 2.14 Trial 3(b) Medium air/water turbulence – Lead analyses for pipes with soft water**

| Sample | Sample type | Cumulative flow | P5(c)[1] Total lead | P5(c)[1] Diss. lead | P6[2] Total lead | P6[2] Diss. lead | P7[2] Total lead | P7[2] Diss. lead | P8[2] Total lead | P8[2] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-test** | | | | | | | | | | |
| Pre-test | 30-MS | - | 1.2 | 1.5 | 1.8 | 1.3 | 3.8 | 1.2 | 1.3 | 1.1 |
| **Post-test** | | | | | | | | | | |
| Day 0 (i) | 1-L flush | 1.0 | 1.4 | 1.2 | 18.7 | 1.1 | 20.4 | 1.0 | 13.8 | 1.1 |
| Day 0 (ii) | 30-MS | 1.25 | 1.5 | 1.7 | 237 | 1.6 | 24.5 | 1.1 | 7.2 | 1.1 |
| Day 0 (iii) | 1-L flush | 2.25 | 0.8 | 1.0 | 25.8 | 0.8 | 2.2 | 0.7 | 1.6 | 0.8 |
| Day 0 (iv) | 30-MS | 2.5 | 1.5 | 1.5 | 49.7 | 1.4 | 2.9 | 1.2 | 4.1 | 1.3 |
| Day 0 (v) | 1-L flush | 3.5 | 1.3 | 1.2 | 1.1 | 0.9 | 1.1 | 0.9 | 2.6 | 0.8 |
| Day 0 (vi) | 30-MS | 3.75 | 1.4 | 1.7 | 17.3 | 1.6 | 3.2 | 1.3 | 3.1 | 1.3 |
| Day 0 (vii) | 1-L flush | 4.75 | 1.1 | 1.1 | 1.4 | 0.9 | 0.8 | 0.9 | 1.4 | 0.8 |
| Day 1 | 30-MS | 293 | 1.2 | 1.4 | 13.5 | 1.6 | 5.9 | 1.3 | 2.8 | 1.4 |
| Day 3 | 30-MS | 1013 | 1.1 | 1.1 | 4.2 | 1.0 | 2.5 | 1.1 | 1.5 | 1.1 |
| Day 8 | 30-MS | 2813 | 1.0 | 0.9 | 2.2 | 1.0 | 1.4 | 0.9 | 1.2 | 1.0 |

Notes:

1. Pipe 5 (control): Pipe length = 3.0 m; pipe volume = 285 ml.
2. Pipes 6, 7 and 8: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml.

**Figure 2.17 Trial 3(b) Medium air/water turbulence – Effluent lead concentration (30-MS)**



### 2.5.5 Trial 3(c) – High rate (12-15 l/min) refill

Trial 3(c) was carried out to investigate refilling and flushing the test pipes at an initial high rate (12-15 l/min). The pipe rig was not designed to allow flows of this rate through the test pipes and had to be modified. Samples were taken via the drainage pipework which required manual operation of the appropriate valves. Accordingly the sample rates and times were less accurate than in the previous trials, and the results should be considered 'indicative'. After passage of 4.75 l, equivalent to approximately 19 pipe volumes, the flow rate was decreased to 6 l/min for the remainder of the trial (i.e. the flow rate maintained throughout Trials 1 and 2).

#### Results

Analyses of the hard and soft feed waters are shown in Figures 2.1 and 2.2, respectively.

Effluent lead concentrations taken from the hard and soft water pipes are shown in Tables 2.13 and 2.14 respectively, and in Figure 2.17.

**Table 2.15 Trial 3(c) High air/water turbulence – Lead analyses for pipes with hard water**

| Sample | Sample type | Cumulative flow | P1[1] Total lead | P1[2] Diss. lead | P2[2] Total lead | P2[2] Diss. lead | P3[2] Total lead | P3[2] Diss. lead | P4(c)[3] Total lead | P4(c)[3] Diss. lead |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-test** | | | | | | | | | | |
| Pre-test | 30-MS | - | 5.3 | 5.0 | 5.8 | 5.1 | 5.4 | 4.5 | 9.0 | 4.1 |
| **Post-test** | | | | | | | | | | |
| Day 0 (i) | 1-L flush | 1.0 | 73.1 | 3.2 | 53.7 | 3.9 | 13.4 | 2.9 | 4.5 | 2.4 |
| Day 0 (ii) | 30-MS | 1.25 | 19.2 | 8.7 | 25.6 | 9.4 | 15.3 | 7.9 | 6.9 | 3.7 |
| Day 0 (iii) | 1-L flush | 2.25 | 9.3 | 3.1 | 18.5 | 3.2 | 10.6 | 2.8 | 6.5 | 2.4 |
| Day 0 (iv) | 30-MS | 2.5 | 14.3 | 8.2 | 30.1 | 8.3 | 26.0 | 7.1 | 9.5 | 6.0 |
| Day 0 (v) | 1-L flush | 3.5 | 6.1 | 2.9 | 22.4 | 3.2 | 18.7 | 2.5 | 3.8 | 2.1 |
| Day 0 (vi) | 30-MS | 3.75 | Samples not analysed | | | | | | | |
| Day 0 (vii) | 1-L flush | 4.75 | Samples not analysed | | | | | | | |
| Day 1 | 30-MS | 293 | 7.6 | 4.9 | 5.8 | 4.8 | 14.4 | 4.0 | 3.9 | 3.7 |
| Day 3 | 30-MS | 1013 | 5.8 | 4.9 | 9.6 | 4.9 | 11.7 | 3.9 | 4.0 | 3.8 |
| Day 8 | 30-MS | 2813 | 13.5 | 5.2 | 6.3 | 5.7 | 12.6 | 4.6 | 4.6 | 4.4 |

Notes:

1. Pipes 1, 2 and 3: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml.
2. Pipe 4 (control): Pipe length = 3.0 m; pipe volume = 285 ml.

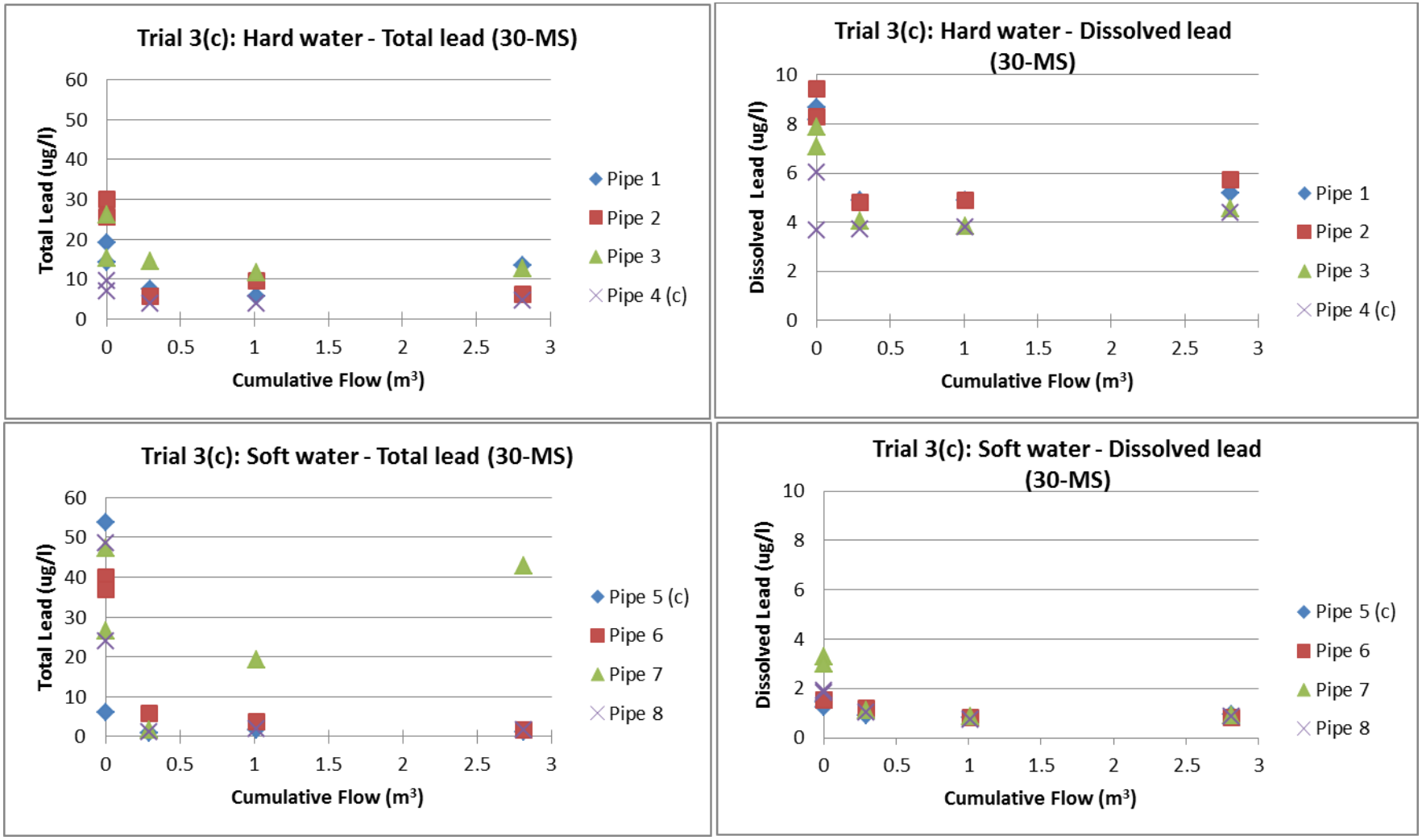
**Table 2.16 Trial 3(c) High air/water turbulence – Lead analyses for pipes with soft water**

| Sample | Sample type | Cumulative flow | P5(c)[1] Total Pb | P5(c)[1] Diss. Pb | P6[2] Total Pb | P6[2] Diss. Pb | P7[2] Total Pb | P7[2] Diss. Pb | P8[2] Total Pb | P8[2] Diss. Pb |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Litres | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l | µg/l |
| **Pre-test** | | | | | | | | | | |
| Pre-test | 30-MS | - | 1.1 | 0.9 | 3.1 | 1.2 | 5.8 | 1.2 | 1.1 | 1.0 |
| **Post-test** | | | | | | | | | | |
| Day 0 (i) | 1-L flush | 1.0 | 99.8 | 1.4 | 135 | 1.3 | 28.6 | 1.4 | 51.3 | 1.2 |
| Day 0 (ii) | 30-MS | 1.25 | 53.8 | 1.5 | 40.1 | 1.6 | 47.3 | 3.3 | 48.6 | 1.8 |
| Day 0 (iii) | 1-L flush | 2.25 | 11.6 | 0.9 | 23.7 | 0.8 | 20.5 | 1.3 | 21.4 | 1.1 |
| Day 0 (iv) | 30-MS | 2.5 | 6.1 | 1.3 | 36.8 | 1.6 | 25.6 | 3.0 | 23.9 | 1.9 |
| Day 0 (v) | 1-L flush | 3.5 | 4.7 | 0.8 | 29.5 | 0.7 | 15.4 | 1.3 | 15.3 | 0.9 |
| Day 0 (vi) | 30-MS | 3.75 | Samples not analysed | | | | | | | |
| Day 0 (vii) | 1-L flush | 4.75 | Samples not analysed | | | | | | | |
| Day 1 | 30-MS | 293 | 0.8 | 0.9 | 5.8 | 1.2 | 1.5 | 1.1 | 1.1 | 1.0 |
| Day 3 | 30-MS | 1013 | 1.6 | 0.8 | 3.6 | 0.8 | 19.3 | 0.8 | 1.9 | 0.7 |
| Day 8 | 30-MS | 2813 | 1.2 | 0.9 | 1.7 | 0.8 | 42.9 | 0.9 | 1.7 | 0.8 |

Notes:

1. Pipe 5 (control): Pipe length = 3.0 m; pipe volume = 285 ml.
2. Pipes 6, 7 and 8: Pipe length = 2.65 m; pipe volume = 252 ml; boundary box/water meter volume = 230-240 ml.

**Figure 2.18 Trial 3(c) High air/water turbulence - Effluent lead concentration (30-MS)**



### 2.5.6 Trial 3 conclusions

The principal conclusions from the third trial are summarised below.

Hard water 30-MS samples:

- Total and dissolved lead concentrations from the control pipe, which was not drained, were generally unaffected by subsequent flow rates of up to 12-15 l/min.

- Total and dissolved lead concentrations from the test pipes increased slightly (compared with both the pre-test and control values) as a result of air/water turbulence at refill flow rates of 1 l/min, 6 l/min and 12-15 l/min. Dissolved lead concentrations returned to pre-test values after the passage of up to 293-1013 litres of water (at 6 l/min); total lead concentrations returned to pre-test values after the passage of up to 293-2813 litres of water (at 6 l/min).

Soft water 30-MS samples:

- Dissolved lead concentrations from the control pipe, which was not drained, were generally unaffected by subsequent flow rates of up to 12-15 l/min.

- Total lead concentrations from the control pipe were generally unaffected by flow rates up to 6.0 l/min but increased significantly due to particulate material at 12-15 l/min. Lead concentrations reduced to pre-test values after the passage of up to 293 litres of water (at 6 l/min).

- Total lead concentrations from the test pipes increased substantially (compared with both the pre-test and control values) as a result of air/water turbulence during refill of the pipes at 1 l/min, 6 l/min and 12-15 l/min, due to significant amounts of particulate lead. The particulate lead could have resulted from disturbance of sediment or by abrasion of deposits attached to the pipe walls. There was significant variation between the pipes; concentrations of particulate lead from Pipe 6 were particularly high. Total lead concentrations returned to pre-test values after the passage of up to 293-1013 litres of water (at 6 l/min).

- Dissolved lead concentrations from the test pipes were largely unaffected by refill flow rates of up to 6 l/min. Concentrations increased at 12-15 l/min but reduced to pre-test values after the passage of up to 293 litres of water (at 6 l/min).

## 2.6 Discussion

### 2.6.1 Trials 1 and 2

Trial 1 simulated installation of water meters which were installed by a procedure simulating real practice and causing significant disturbance to the test pipes; Trial 2 simulated meter installation with minimal disturbance. In Trial 1, control pipes were temporarily relocated during the installation procedure; in Trial 2, control pipes remained in place during the installation procedure.

#### Hard Water Trials

Mean 30-MS effluent lead concentrations for the hard water trials are summarised in Table 2.17 and Figure 2.19.

#### Trial 1

The mean total lead concentrations[5] (30-MS) from the test pipes increased from 7.4 µg/l to 44.9 µg/l immediately following the water meter installation. This increase was largely due to particulate material which was calculated as 31.4 µg/l. For comparison, total lead concentrations from the control pipe increased from 6.8 µg/l to 71.6 µg/l, with particulate lead calculated as 54.5 µg/l.

Mean total lead concentrations from the test and control pipes were reduced to 21.5 µg/l and 29.7 µg/l respectively, following the passage of 3.7 litres of water. This change was a result of reduced particulate lead, as mean total *dissolved* lead concentrations were largely unaffected by the passage of this volume of water (14.3 µg/l cf. 13.5 µg/l immediately following installation).

Mean 30-MS total lead concentrations returned to approximate pre-installation values after 3-8 days operation of the lead rig, following the passage of 892-2,693 litres of water.

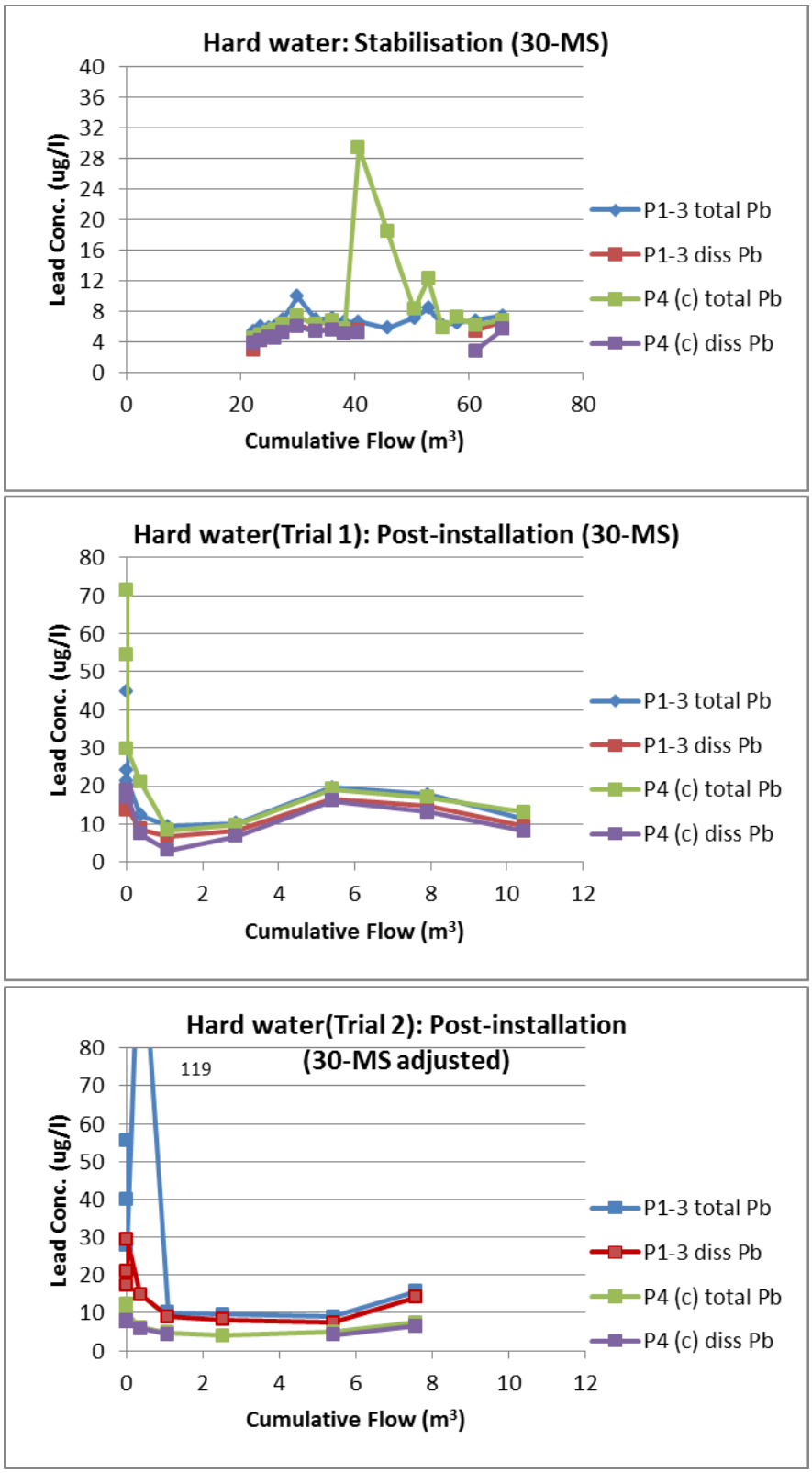
A notable observation from Trial 1 was the increase in lead concentrations from the control pipe – comparable with the test pipes – as a result of the disturbance caused by its temporary relocation.

**Table 2.17 Trials 1 and 2: Hard water – Summary of mean lead concentrations (30-MS)**

| Sample | Vol. water passed (l) | Test Pipes 1-3 | | | Control Pipe 4 | | |
|---|---|---|---|---|---|---|---|
| | | Total (µg/l) | Dissolved (µg/l) | Particulate (µg/l) | Total (µg/l) | Dissolved (µg/l) | Particulate (µg/l) |
| **Trial 1** | | | | | | | |
| Pre-installation | - | 7.4 | 6.7 | 0.7 | 6.8 | 5.6 | 1.2 |
| Post-installation Day 0(i) | 1.2 | 44.9 | 13.5 | 31.4 | 71.6 | 17.1 | 54.5 |
| Day 0(iii) | 3.7 | 21.5 | 14.3 | 7.2 | 29.7 | 17.5 | 12.2 |
| Day 1 | 172 | 12.3 | 8.7 | 3.6 | 21.2 | 7.4 | 13.8 |
| Day 3 | 892 | 9.5 | 6.8 | 2.7 | 8.3 | 3.1 | 5.2 |
| Day 8 | 2,693 | 10.2 | 8.2 | 2.0 | 9.8 | 6.8 | 3.0 |
| **Trial 2** | | | | | | | |
| Pre-installation | - | 5.4 | 4.5 | 0.9 | 8.2 | 3.1 | 5.1 |
| Post-installation Day 0(i) | 1.5/1.2 | 29.1 (55.4*) | 11.5 (21.0*) | 17.6 (34.4*) | 9.9 | 7.9 | 2.0 |
| Day 0(iii) | 4.5/3.7 | 15.0 (27.9*) | 15.8 (29.3*) | - | 9.5 | 7.6 | 1.9 |
| Day 1 | 172 | 61.5 (118.7*) | 8.1 (14.9*) | 53.4 (103.8*) | 6.1 | 5.9 | 0.2 |
| Day 3 | 892 | 5.3 (10.1*) | 4.7 (8.9*) | 0.6 (1.2*) | 4.7 | 4.3 | 0.4 |
| Day 8 | 2,693 | 5.0 (9.5*) | 4.3 (8.1*) | 0.7 (1.4*) | 4.0 | 0.3 | 3.7 |

Note: *Value adjusted for greater volume of water sampled and to allow comparison with corresponding value from Trial 1.

**Figure 2.19 Trials 1 and 2: Hard water - Mean concentration of lead (30-MS)**



## Trial 2

The mean total lead concentrations[5] (30-MS) from the test pipes increased immediately following the water meter installation from 5.4 µg/l to 55.4µg/l. This increase was largely due to particulate material which was calculated as 34.4 µg/l. For comparison, total lead concentrations from the control pipe increased from 8.2 µg/l to 9.9 µg/l, with particulate lead calculated as 2.0 µg/l.

Mean total lead concentrations from the test and control pipes were reduced to 27.9 µg/l and 9.5 µg/l respectively, following the passage of 3.7/4.5 litres of water. This change was a result of reduced particulate lead, as mean total *dissolved* lead concentrations were largely unaffected by the passage of water, 29.3 µg/l cf. 21.0 µg/l immediately following installation for the test pipes and 7.6 µg/l cf. 7.9 µg/l (control pipe).

Mean 30-MS total lead concentrations returned to approximate pre-installation values after 8 days operation of the lead rig for the test pipes (following the passage of 2,693 litres of water) and 1-3 days operation for the control pipe (following the passage of 172-892 litres of water.

A notable observation from Trial 2, where the control pipe was not removed from the rig, was the smaller increase in lead concentrations from the control pipe compared with the test pipes and also compared with the lead concentrations measured in Trial 1 where the control pipe was temporarily removed from the rig.

## Soft Water Trials

Mean 30-MS effluent lead concentrations for the soft water trials are summarised in Table 2.18 and Figure 2.20.

## Trial 1

In Trial 1, mean 30-MS total lead concentrations from the test pipes increased from 2.7 µg/l to 160.7 µg/l immediately following installation of the water meter. This increase was largely due to particulate material (157.5 µg/l). For comparison, total lead concentrations from the control pipe increased from 2.1 µg/l to 109.0 µg/l, with 106.0 µg/l particulate lead.

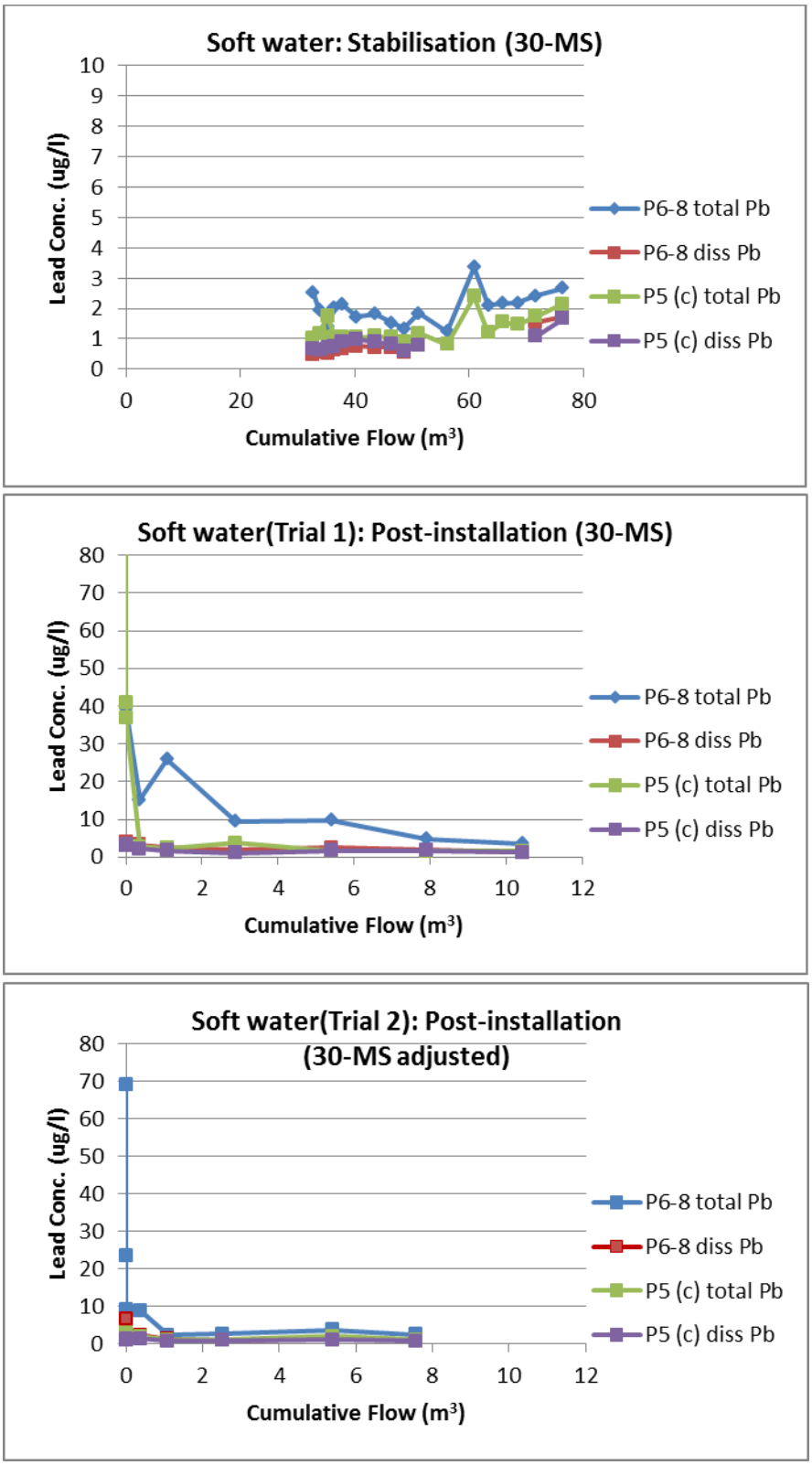
[5] Value adjusted for greater volume of water sampled.

**Table 2.18 Trials 1 and 2: Soft water – Summary of mean lead concentrations (30-MS)**

| Sample | Vol. water passed (l) | Test Pipes 6-8 | | | Control Pipe 5 | | |
|---|---|---|---|---|---|---|---|
| | | Total (µg/l) | Dissolved (µg/l) | Particulate (µg/l) | Total (µg/l) | Dissolved (µg/l) | Particulate (µg/l) |
| **Trial 1** | | | | | | | |
| Pre-installation | - | 2.7 | 1.7 | 1.0 | 2.1 | 1.7 | 0.4 |
| Post-installation Day 0 (i) | 1.2 | 160.7 | 3.2 | 157.5 | 109.0 | 3.0 | 106.0 |
| Day 0 (iii) | 3.7 | 39.5 | 4.0 | 35.5 | 37.0 | 3.2 | 33.8 |
| Day 1 | 172 | 15.2 | 3.3 | 11.9 | 2.8 | 2.1 | 0.7 |
| Day 3 | 892 | 26.0 | 2.5 | 23.5 | 2.4 | 1.8 | 0.6 |
| Day 8 | 2,693 | 9.5 | 1.8 | 7.7 | 3.8 | 1.2 | 2.6 |
| **Trial 2** | | | | | | | |
| Pre-installation | - | 1.2 | 0.7 | 0.5 | 1.1 | 0.9 | 0.2 |
| Post-installation Day 0 (i) | 1.5/1.2 | 41.0 (68.9*) | 4.0 (6.7*) | 37.0 (62.2*) | 2.7 | 1.3 | 1.4 |
| Day 0 (iii) | 4.5/3.7 | 5.4 (9.0*) | 1.6 (2.6*) | 3.8 (6.4*) | 2.8 | 1.1 | 1.7 |
| Day 1 | 172 | 5.4 (8.9*) | 1.5 (2.4*) | 3.9 (6.5*) | 2.0 | 1.3 | 0.7 |
| Day 3 | 892 | 1.4 (2.3*) | 0.7 (1.2*) | 0.7 (1.1*) | 1.1 | 0.8 | 0.3 |
| Day 8 | 2,693 | 1.6 (2.6*) | 0.6 (0.9*) | 1.0 (1.7*) | 1.0 | 0.9 | 0.1 |

Note: *Value adjusted to allow comparison with corresponding value from Trial 1.

**Figure 2.20 Trials 1 and 2: Soft water - mean concentration of lead (30-MS)**



Mean 30-MS dissolved lead concentration for the test pipes approached the pre-installation value after about 8 days operation of the test rig with passage of 2,693 litres of water. The mean total lead concentration reduced with the passage of water but remained higher than the pre-installation value. For the control pipe, the mean 30-MS total lead concentration approached the pre-installation value after 1 days operation and the passage of 172 litres of water.

As for the hard water test pipes in Trial 1, the lead concentrations from the control pipe increased was comparable with the test pipes, the increase presumed to be as a result of the disturbance caused by temporary relocation of the control pipe.

## Trial 2

The mean 30-MS total lead concentrations[6] from the test pipes increased from 1.2 µg/l to 68.9 µg/l immediately following the water meter installation. This increase was largely due to particulate material (62.2 µg/l). For comparison, total lead concentration from the control pipe increased from 1.1 µg/l to 2.7 µg/l, with particulate lead concentration of 1.4 µg/l.

Mean total lead concentrations from the test pipes reduced to 9.0 µg/l, following the passage of 4.5 litres of water. Mean total lead concentrations from the control pipes was unchanged. Mean dissolved lead concentration from the test pipes showed a reduction from 6.7 µg/l to 2.6 µg/l after the passage of 4.5 litres of water, but the concentration from the control pipe - which was comparable to the pre-installation value - was unaffected.

The mean 30-MS total lead concentration for the test pipes had returned to approximate pre-installation values after 3 days operation of the lead rig, following the passage of 892 litres of water.

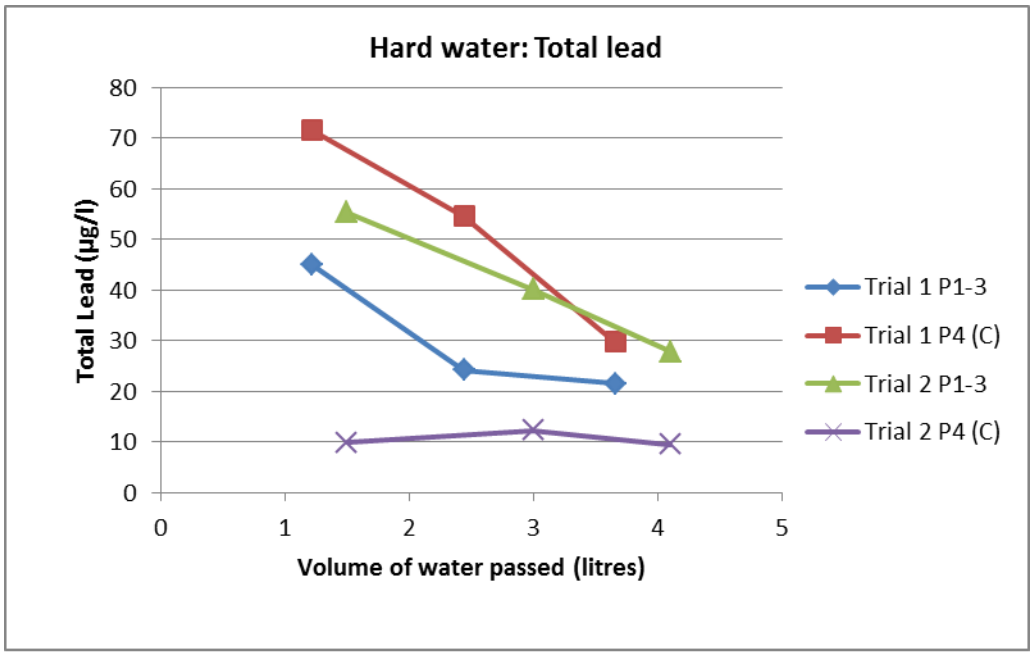
A notable observation from Trial 2 was the significantly smaller increase in lead concentrations from the control pipe as a result of the smaller disturbance caused by the installation procedure.

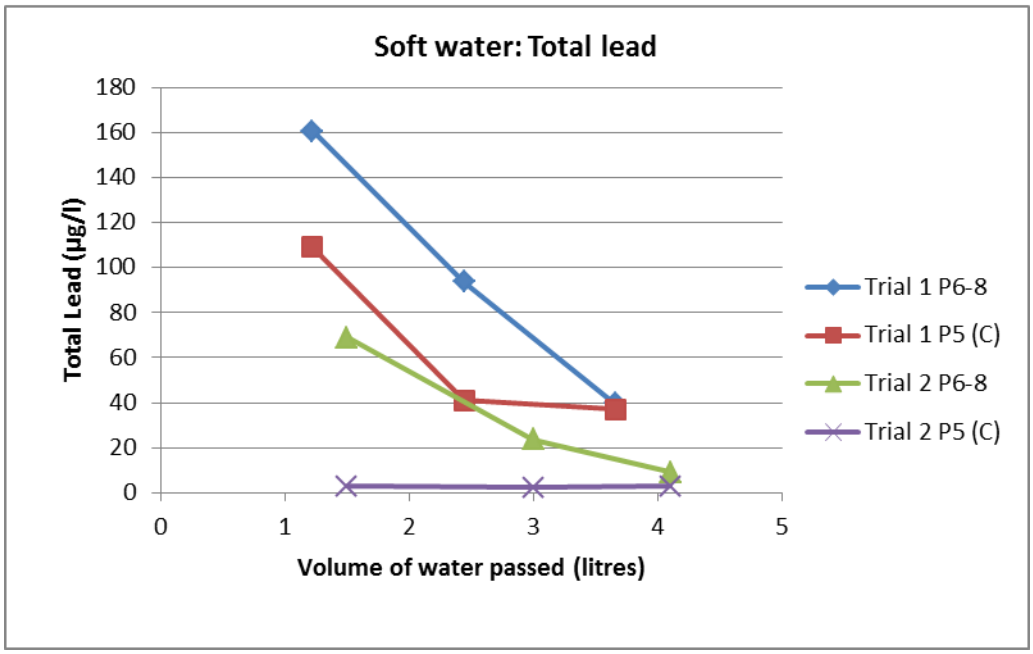
## Comparison of Trials 1 and 2

A summary of the mean 30-MS total lead concentrations measured on Day 0 following the installation of water meters for Trials 1 and 2 is shown in Figure 2.21.

[6] Value adjusted for greater volume of water sampled.

**Figure 2.21 Trials 1 and 2: Comparison of mean total lead concentrations for hard and soft water (30-MS, Day 0)**




From the summary data presented in Figure 2.21, the following points are noted from the trials with the hard water:

- Lead concentrations increased substantially following the installation of water meters in both Trial 1 and Trial 2 irrespective of the degree of disturbance during the installation procedure.

- In Trial 1, the lead concentrations from the control pipe also increased substantially due to the temporary relocation of the pipe whilst the water meters were installed in the test pipes. It was noted that some water drained from the pipe during the relocation and postulated that the increase in lead was due in part to the turbulence in the pipe when refilled.

- In Trial 2, the lead concentrations from the control pipe increased only slightly following the installation of the water meters in the test pipes (with minimal disturbance).

The following points are noted from the trials with the soft water:

- In Trial 1, the lead concentrations from the test pipes increased substantially following the installation of water meters; the lead concentrations from the control pipe also increased substantially due to the temporary relocation of the pipe whilst the water meters were installed in the test pipes. As noted above, it was postulated that the increase in lead from the control pipe was due in part to turbulence when refilled.

- In Trial 2, the lead concentrations from the test pipes increased following the installation of water meters but to a lesser extent than observed in Trial 1.

- In Trial 2, the lead concentrations from the control pipe were unaffected by the installation of the water meters in the test pipes.

### 2.6.2 Trial 3

Trial 3 investigated the effect of air/water turbulence on the protective lead phosphate layer in the lead pipes.

Tests were carried out on partially drained pipes, refilled at rates of 1 l/min (low rate), 6 l/min (medium rate) and 12-15 l/min (high rate). Comparative tests were carried out on the control pipes which remained full of water throughout the tests.

#### Hard water

Summaries of 30-MS total and dissolved lead concentrations for the hard water tests are shown in Table 2.19, Table 2.20 and Table 2.21.

The results from Table 2.19 show increasing mean values for total lead concentrations from the test pipes as the flushing rate was increased up to 12-15 l/min. Concentrations reduced as the volume of water that was passed through the pipes increased, and generally measured less than 10 µg/l after the passage of 293 litres.

The results from Table 2.20 show slight increases in dissolved lead concentrations on Day 0 immediately following refilling of the test pipes, although only Trial 3(b) exceeded 10 µg/l (up to 12.6 µg/l). Pre-test values were attained following the passage of 293 litres of water.

**Table 2.19 Trial 3: Hard water - Summary of total lead concentrations (30-MS)**

| Sample | Vol. water passed (l) | Trial 3(a)[1] | | Trial 3(b)[2] | | Trial 3(c)[3] | |
|---|---|---|---|---|---|---|---|
| | | Pipes 1-3[4] (µg/l) | Pipe 4(c) (µg/l) | Pipes 1-3[4] (µg/l) | Pipe 4(c) (µg/l) | Pipes 1-3[4] (µg/l) | Pipe 4(c) (µg/l) |
| Pre-test | - | 6.0 | 4.6 | 6.4 | 4.9 | 5.5 | 9.0 |
| Day 0 (ii) | 1.25 | 15.6 | 6.0 | 17.3 | 11.6 | 20.0 | 6.9 |
| Day 0 (iv) | 2.5 | 9.5 | 6.1 | 12.4 | 9.6 | 23.5 | 9.5 |
| Day 0 (vi) | 3.75 | 8.9 | 6.2 | 12.3 | 10.1 | - | - |
| Day 1 | 293 | 6.5 | 4.5 | 10.0 | 7.7 | 9.2 | 3.9 |
| Day 3 | 1013 | 6.0 | 4.1 | 6.4 | 4.6 | 9.0 | 4.0 |
| Day 8 | 2813 | 6.4 | 4.9 | 5.7 | 4.8 | 10.8 | 4.6 |

Notes:

1. Day 0 (ii) and (iv) = 1 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
2. Day 0 (ii) and (iv) = 6 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
3. Day 0 (ii) and (iv) = 12-15 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
4. Mean value from Pipes 1 to 3.

**Table 2.20 Trial 3: Hard water - Summary of dissolved lead concentrations (30-MS)**

| Sample | Vol. water passed (l) | Trial 3(a)[1] | | Trial 3(b)[2] | | Trial 3(c)[3] | |
|---|---|---|---|---|---|---|---|
| | | Pipes 1-3[4] (µg/l) | Pipe 4(c) (µg/l) | Pipes 1-3[4] (µg/l) | Pipe 4(c) (µg/l) | Pipes 1-3[4] (µg/l) | Pipe 4(c) (µg/l) |
| Pre-test | - | 5.5 | 4.6 | 5.7 | 5.0 | 4.9 | 4.1 |
| Day 0 (ii) | 1.25 | 9.1 | 5.5 | 12.6 | 10.2 | 8.7 | 3.7 |
| Day 0 (iv) | 2.5 | 8.8 | 6.1 | 10.6 | 9.9 | 7.8 | 6.0 |
| Day 0 (vi) | 3.75 | 8.3 | 6.0 | 11.2 | 9.4 | - | - |
| Day 1 | 293 | 6.1 | 4.5 | 8.4 | 7.0 | 4.6 | 3.7 |
| Day 3 | 1013 | 5.5 | 4.3 | 5.2 | 4.3 | 4.6 | 3.8 |
| Day 8 | 2813 | 5.7 | 5.0 | 4.5 | 3.9 | 5.2 | 4.4 |

Notes:

1. Day 0 (ii) and (iv) = 1 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
2. Day 0 (ii) and (iv) = 6 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
3. Day 0 (ii) and (iv) = 12-15 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
4. Mean value from Pipes 1 to 3.

**Table 2.21 Trial 3: Hard water - Comparison of total and dissolved lead for Days 1, 3 and 8**

| Sample | Sample type | Trial 3(a) | | | | Trial 3(b) | | | | Trial 3(c) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4(c) | P1 | P2 | P3 | P4(c) | P1 | P2 | P3 | P4(c) |
| **Total lead (µg/l)** | | | | | | | | | | | | | |
| Pre-test | 30-MS | 6.3 | 6.2 | 5.5 | 4.6 | 6.9 | 7.3 | 5.0 | 4.9 | 5.3 | 5.8 | 5.4 | 9.0 |
| Day 1 | 30-MS | 6.9 | 7.6 | 5.0 | 4.5 | 10.6 | 10.9 | 8.6 | 7.7 | 7.6 | 5.8 | 14.4 | 3.9 |
| Day 3 | 30-MS | 6.5 | 6.3 | 5.1 | 4.1 | 7.5 | 6.2 | 5.4 | 4.6 | 5.8 | 9.6 | 11.7 | 4.0 |
| Day 8 | 30-MS | 6.9 | 7.3 | 5.0 | 4.9 | 6.3 | 6.1 | 4.7 | 4.8 | 13.5 | 6.3 | 12.6 | 4.6 |
| **Dissolved lead (µg/l)** | | | | | | | | | | | | | |
| Pre-test | 30-MS | 5.9 | 6.0 | 4.7 | 4.6 | 6.0 | 6.3 | 4.9 | 5.0 | 5.0 | 5.1 | 4.5 | 4.1 |
| Day 1 | 30-MS | 6.5 | 6.4 | 5.3 | 4.5 | 8.9 | 8.9 | 7.5 | 7.0 | 4.9 | 4.8 | 4.0 | 3.7 |
| Day 3 | 30-MS | 6.3 | 6.0 | 4.3 | 4.3 | 5.5 | 5.6 | 4.6 | 4.3 | 4.9 | 4.9 | 3.9 | 3.8 |
| Day 8 | 30-MS | 6.0 | 6.3 | 4.9 | 5.0 | 4.9 | 4.7 | 3.8 | 3.9 | 5.2 | 5.7 | 4.6 | 4.4 |

Comparison of the lead concentrations in Table 2.19 and Table 2.20 show that the increase in total lead was due largely to particulate lead, with the highest concentrations (11.3-15.7 µg/l) being calculated for the pipes refilled at the highest rate on Day 0.

Table 2.21 compares the lead concentrations from the three flushing trials on Days 1, 3 and 8 (when the rig was operated at 6 l/min for all trials). The dissolved lead concentrations from each trial approximately returned to pre-test values by Day 1 (293 litres); pre-test total lead concentrations for Trial 3(a) were also recovered by Day 1. Total lead concentrations for Trial 3(b) were slightly elevated on Day 1 (up to 10.9 µg/l) but recovered pre-test values by Day 3. Total lead concentrations for Trial 3(c) were more variable, with values from the test pipes measuring 6-14 µg/l on both Day 1 and Day 8.

Lead concentrations from the test pipes were generally greater than those from the control pipe (that were largely comparable to pre-test values).

Overall, it appears that air/water turbulence during flushing can cause elevated concentrations of total lead (largely due to particulate material) and that values may increase at higher flushing rates.

## Soft water

Summaries of 30-MS total and dissolved lead concentrations for the soft water tests are shown in Table 2.22, Table 2.23 and Table 2.24.

The results from Table 2.22 show some significant increases for mean total lead concentrations from the test pipes on Day 0 for all flushing rates. This was due in part to particularly high (and possibly atypical) lead concentrations measured from Pipe 6 for Runs 3(a) and 3(b). Removing Pipe 6 data from the mean values showed lesser increases in lead concentrations for Runs 3(a) and 3(b), with only the initial values (Day 0(ii)) measuring slightly above 10 µg/l. The initial total lead concentration for Run 3(c) was 45.3 µg/l but a comparable increase was measured from the control pipe, possibly indicating an effect of flushing at the higher velocity and not due to air/water turbulence.

Concentrations generally reduced as the volume of water passed through the pipes increased, and measured less than 10 µg/l after the passage of 293 litres, although the concentration of total lead increased subsequently for Run 3(c) due to increased concentrations from Pipe 7.

The results from Table 2.23 show slight increases in dissolved lead concentrations on Day 0 immediately following refilling of the test pipes, but no value exceeded 5 µg/l and pre-test values were attained following the passage of 2.5-3.75 litres of water.

Comparison of the lead concentrations in Table 2.22 and Table 2.23 show that the increase in total lead was due largely to concentrations of particulate lead.

**Table 2.22 Trial 3: Soft water - Summary of total lead concentrations (30-MS)**

| Sample | Vol. water passed (l) | Trial 3(a)[1] | | | Trial 3(b)[2] | | | Trial 3(c)[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pipe 5(c) (µg/l) | Pipes 6-8[4] (µg/l) | Pipes 7-8[5] (µg/l) | Pipe 5(c) (µg/l) | Pipes 6-8[4] (µg/l) | Pipes 7-8[5] (µg/l) | Pipe 5(c) (µg/l) | Pipes 6-8[4] (µg/l) | Pipes 7-8[5] (µg/l) |
| Pre-test | - | 2.1 | 3.0 | 2.0 | 1.2 | 2.3 | 1.7 | 1.1 | 3.3 | 2.3 |
| Day 0 (ii) | 1.25 | 2.3 | 27.6 | 10.5 | 1.5 | 89.6 | 10.6 | 53.8 | 45.3 | 32.0 |
| Day 0 (iv) | 2.5 | 2.5 | 104 | 8.2 | 1.5 | 18.9 | 2.3 | 6.1 | 29.1 | 16.8 |
| Day 0 (vi) | 3.75 | 2.2 | 75.2 | 9.2 | 1.4 | 7.9 | 2.1 | - | - | - |
| Day 1 | 293 | 2.1 | 8.6 | 7.0 | 1.2 | 7.4 | 2.9 | 0.8 | 2.8 | 0.9 |
| Day 3 | 1013 | 1.4 | 2.3 | 1.8 | 1.1 | 2.7 | 1.3 | 1.6 | 8.3 | 7.1 |
| Day 8 | 2813 | 1.2 | 2.3 | 1.7 | 1.0 | 1.6 | 0.9 | 1.2 | 15.4 | 14.9 |

Notes:

1. Day 0 (ii) and (iv) = 1 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
2. Day 0 (ii) and (iv) = 6 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
3. Day 0 (ii) and (iv) = 12-15 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
4. Mean values from Pipes 6 to 8.
5. Mean values from Pipes 7 to 8.

**Table 2.23 Trial 3: Soft water - Summary of dissolved lead concentrations (30-MS)**

| Sample | Vol. water passed (l) | Trial 3(a)[1] | | | Trial 3(b)[2] | | | Trial 3(c)[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pipe 5(c) (µg/l) | Pipes 6-8[4] (µg/l) | Pipes 7-8[5] (µg/l) | Pipe 5(c) (µg/l) | Pipes 6-8[4] (µg/l) | Pipes 7-8[5] (µg/l) | Pipe 5(c) (µg/l) | Pipes 6-8[4] (µg/l) | Pipes 7-8[5] (µg/l) |
| Pre-test | - | 1.8 | 2.0 | 1.2 | 1.5 | 1.2 | 0.8 | 0.9 | 1.2 | 0.7 |
| Day 0 (ii) | 1.25 | 1.9 | 4.1 | 3.4 | 1.7 | 1.3 | 0.7 | 1.5 | 2.2 | 1.7 |
| Day 0 (iv) | 2.5 | 2.1 | 3.0 | 2.1 | 1.5 | 1.3 | 0.8 | 1.3 | 2.1 | 1.6 |
| Day 0 (vi) | 3.75 | 2.2 | 2.2 | 1.7 | 1.7 | 1.4 | 0.9 | - | - | - |
| Day 1 | 293 | 1.7 | 2.1 | 1.4 | 1.4 | 1.4 | 0.9 | 0.9 | 1.1 | 0.7 |
| Day 3 | 1013 | 1.4 | 1.4 | 0.9 | 1.1 | 1.1 | 0.7 | 0.8 | 0.8 | 0.5 |
| Day 8 | 2813 | 1.5 | 1.2 | 0.8 | 0.9 | 1.0 | 0.6 | 0.9 | 0.9 | 0.6 |

Notes:

1. Day 0 (ii) and (iv) = 1 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
2. Day 0 (ii) and (iv) = 6 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
3. Day 0 (ii) and (iv) = 12-15 l/min; Day 0 (vi) and Days 1, 3 and 8 = 6 l/min.
4. Mean values from Pipes 6 to 8.
5. Mean values from Pipes 7 to 8.

**Table 2.24 Trial 3: Soft water - Comparison of total and dissolved lead for Days 1, 3 and 8**

| Sample | Sample type | Trial 3(a) | | | | Trial 3(b) | | | | Trial 3(c) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P5(c) | P6 | P7 | P8 | P5(c) | P6 | P7 | P8 | P5(c) | P6 | P7 | P8 |
| **Total lead (µg/l)** | | | | | | | | | | | | | |
| Pre-test | 30-MS | 2.1 | 2.9 | 3.8 | 2.3 | 1.2 | 1.8 | 3.8 | 1.3 | 1.1 | 3.1 | 5.8 | 1.1 |
| Day 1 | 30-MS | 2.1 | 4.8 | 17.6 | 3.4 | 1.2 | 13.5 | 5.9 | 2.8 | 0.8 | 5.8 | 1.5 | 1.1 |
| Day 3 | 30-MS | 1.4 | 1.7 | 3.4 | 1.9 | 1.1 | 4.2 | 2.5 | 1.5 | 1.6 | 3.6 | 19.3 | 1.9 |
| Day 8 | 30-MS | 1.2 | 1.8 | 3.8 | 1.3 | 1.0 | 2.2 | 1.4 | 1.2 | 1.2 | 1.7 | 42.9 | 1.7 |
| **Dissolved lead (µg/l)** | | | | | | | | | | | | | |
| Pre-test | 30-MS | 1.8 | 2.2 | 1.7 | 1.9 | 1.5 | 1.3 | 1.2 | 1.1 | 0.9 | 1.2 | 1.2 | 1.0 |
| Day 1 | 30-MS | 1.7 | 2.2 | 2.1 | 2.0 | 1.4 | 1.6 | 1.3 | 1.4 | 0.9 | 1.2 | 1.1 | 1.0 |
| Day 3 | 30-MS | 1.4 | 1.7 | 1.2 | 1.4 | 1.1 | 1.0 | 1.1 | 1.1 | 0.8 | 0.8 | 0.8 | 0.7 |
| Day 8 | 30-MS | 1.5 | 1.3 | 1.2 | 1.1 | 0.9 | 1.0 | 0.9 | 1.0 | 0.9 | 0.8 | 0.9 | 0.8 |

Table 2.24 compares the lead concentrations from the three flushing trials on Days 1, 3 and 8 (when the rig was operated at 6 l/min for all trials). The dissolved lead concentrations from each trial returned to pre-test values by Day 1 (293 litres).

Total lead concentrations showed more variability, with notable elevated values for each trial. Excluding these elevated values, lead concentrations were comparable to pre-test values by Day 1 (293 litres) with values less than 6 µg/l (although concentrations from Pipe 7 subsequently increased). Lead concentrations from the control pipe showed little change from the pre-test values.

Overall, it appears that air/water turbulence during flushing can cause elevated concentrations of total lead, largely due to particulate material. Lead concentrations in individual samples can be substantially elevated as a result of particulate material.

### 2.6.3 Comparison of Trial 1 and Trial 3

Table 2.25 and Table 2.26 compare the results for Trial 1 (when the installation procedure for the water meters caused significant disturbance to the test pipes and the control pipes were temporarily relocated during the installation) and Trial 3(b). The rig was operated at 6 l/min for both trials.

#### Hard water

Comparison of the results for the hard water (Table 2.25) show that total lead concentrations for the test pipes were significantly greater for Trial 1 than Trial 3(b) indicating that physical disturbance during the installation procedure was responsible for a larger proportion of the increase than the effect of air/water turbulence. Total lead concentrations had generally reduced to around 10 µg/l or less by Day 1 (293 litres), when a large proportion of the total concentration was due to dissolved lead.

The total lead concentrations from the control pipe were substantially greater for Trial 1, indicating that the increase was due to physical disturbance during the relocation process as well as any effect of air/water turbulence.

Dissolved lead concentrations were similar for both trials, with slightly elevated concentrations on Day 0 reducing to less than 10 µg/l by Day 1.

#### Soft water

Comparison of the results for the soft water (Table 2.26) show that total lead concentrations for the test pipes were significantly greater for Trial 1 than Trial 3(b) indicating that physical disturbance during the installation procedure was responsible for a larger proportion of the increase than the effect of air/water turbulence. Lead concentrations from Pipe 6 were substantially greater than from Pipes 7 and 8 in both trials. Total lead concentrations generally

reduced to less than 10 µg/l by Day 1 (293 litres) for both trials, other than for Pipes 6 and 7 which remained above 10 µg/l until after Day 8.

Total lead concentrations from the control pipe were substantially greater for Trial 1, indicating that the increase was due to physical disturbance during the relocation process as well as any effect of air/water turbulence.

Dissolved lead concentrations were slightly higher for Trial 1 but always less than 5 µg/l.

**Table 2.25 Comparison of Trial 1 and Trial 3(b) (both at 6 l/min): Hard water**

| Sample | Sample type | Trial 1 | | | | Trial 3(b) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4(c) | P1 | P2 | P3 | P4(c) |
| **Total lead (µg/l)** | | | | | | | | | |
| Pre-test | 30-MS | 7.8 | 8.2 | 6.2 | 6.8 | 6.9 | 7.3 | 5.0 | 4.9 |
| Day 0 (ii) | 30-MS | 54.4 | 37.7 | 42.7 | 71.6 | 18.5 | 16.3 | 17.0 | 11.6 |
| Day 0 (iv) | 30-MS | 29.2 | 21.5 | 21.9 | 54.6 | 14.1 | 13.8 | 9.2 | 9.6 |
| Day 0 (vi) | 30-MS | 27.3 | 18.8 | 18.5 | 29.7 | 13.2 | 14.3 | 9.5 | 10.1 |
| Day 1 | 30-MS | 18.3 | 9.9 | 8.8 | 21.2 | 10.6 | 10.9 | 8.6 | 7.7 |
| Day 3 | 30-MS | 12.3 | 7.9 | 8.2 | 8.3 | 7.5 | 6.2 | 5.4 | 4.6 |
| Day 8 | 30-MS | 12.0 | 10.2 | 8.4 | 9.8 | 6.3 | 6.1 | 4.7 | 4.8 |
| **Dissolved lead (µg/l)** | | | | | | | | | |
| Pre-test | 30-MS | 7.1 | 7.3 | 5.6 | 5.6 | 6.0 | 6.3 | 4.9 | 5.0 |
| Day 0 (ii) | 30-MS | 16.5 | 15.5 | 8.6 | 17.1 | 13.6 | 14.1 | 10.0 | 10.2 |
| Day 0 (iv) | 30-MS | 16.7 | 15.8 | 11.6 | 19.0 | 11.0 | 12.4 | 8.4 | 9.9 |
| Day 0 (vi) | 30-MS | 16.0 | 15.1 | 11.7 | 17.5 | 11.9 | 12.7 | 9.1 | 9.4 |
| Day 1 | 30-MS | 9.8 | 9.1 | 7.3 | 7.4 | 8.9 | 8.9 | 7.5 | 7.0 |
| Day 3 | 30-MS | 7.7 | 7.2 | 5.5 | 3.1 | 5.5 | 5.6 | 4.6 | 4.3 |
| Day 8 | 30-MS | 9.2 | 8.5 | 6.8 | 6.8 | 4.9 | 4.7 | 3.8 | 3.9 |

**Table 2.26 Comparison of Trial 1 and Trial 3(b) (both at 6 l/min): Soft water**

| Sample | Sample type | Trial 1 | | | | Trial 3(b) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | P5(c) | P6 | P7 | P8 | P5(c) | P6 | P7 | P8 |
| **Total lead (µg/l)** | | | | | | | | | |
| Pre-test | 30-MS | 2.1 | 2.5 | 3.2 | 2.3 | 1.2 | 1.8 | 3.8 | 1.3 |
| Day 0 (ii) | 30-MS | 109 | 419 | 48.4 | 14.8 | 1.5 | 237 | 24.5 | 7.2 |
| Day 0 (iv) | 30-MS | 40.9 | 253 | 18.2 | 9.7 | 1.5 | 49.7 | 2.9 | 4.1 |
| Day 0 (vi) | 30-MS | 37.0 | 81.7 | 25.7 | 11.0 | 1.4 | 17.3 | 3.2 | 3.1 |
| Day 1 | 30-MS | 2.8 | 25.5 | 15.0 | 5.2 | 1.2 | 13.5 | 5.9 | 2.8 |
| Day 3 | 30-MS | 2.4 | 19.1 | 56.2 | 2.7 | 1.1 | 4.2 | 2.5 | 1.5 |
| Day 8 | 30-MS | 3.8 | 13.0 | 13.1 | 2.4 | 1.0 | 2.2 | 1.4 | 1.2 |
| **Dissolved lead (µg/l)** | | | | | | | | | |
| Pre-test | 30-MS | 1.7 | 1.6 | 2.1 | 1.5 | 1.5 | 1.3 | 1.2 | 1.1 |
| Day 0 (ii) | 30-MS | 3.0 | 3.1 | 3.8 | 2.8 | 1.7 | 1.6 | 1.1 | 1.1 |
| Day 0 (iv) | 30-MS | 3.3 | 4.0 | 4.7 | 3.4 | 1.5 | 1.4 | 1.2 | 1.3 |
| Day 0 (vi) | 30-MS | 3.2 | 3.6 | 4.9 | 3.4 | 1.7 | 1.6 | 1.3 | 1.3 |
| Day 1 | 30-MS | 2.1 | 3.7 | 3.6 | 2.5 | 1.4 | 1.6 | 1.3 | 1.4 |
| Day 3 | 30-MS | 1.8 | 2.6 | 2.7 | 2.3 | 1.1 | 1.0 | 1.1 | 1.1 |
| Day 8 | 30-MS | 1.2 | 2.2 | 1.9 | 1.3 | 0.9 | 1.0 | 0.9 | 1.0 |

## 2.7 Statistical analysis

Lead concentrations from Trials 1 and 2 were compared to identify whether results were significantly different. Specifically, the following comparisons were made:

- Trial 1: 30-MS lead concentrations were compared with stabilised lead concentrations measured during the pre-installation phase; also the results from the test pipes (P1-P3, P6-P8) were compared with the results from the control pipes (P4(c), P5(c)).

- Trial 2: 30-MS lead concentrations were compared with stabilised lead concentrations measured towards the end of Trial 1 (16/08/13-14/10/13); also the results from the test pipes (P1-P3, P6-P8) were compared with the results from the control pipes (P4(c), P5(c)).

- Trials 1 & 2: Mean 30-MS lead concentrations from the test pipes (P1-P3, P6-P8) were compared with the results from the control pipes (P4(c), P5(c)).

### 2.7.1 Methodology

Most statistical tests require that data follow a normal distribution. However this is unlikely to be the case for the measured lead concentrations from the pipe rig because: i) concentrations cannot be lower than 0, and ii) there were a large number of outliers (extremely high concentrations) which would not be expected if the data followed a normal distribution. Logarithmic values of data with these characteristics are often approximately normally distributed, statistical analysis was therefore carried out on the logarithmic value of lead concentration.

T-tests were used to test whether differences in logged lead concentrations were statistically significant. A threshold value of $p$=0.05 was used, such that calculated values of $p$ <0.05 were taken to indicate statistically significant results. Testing was done using the 't-test' function built into MS Excel unless otherwise specified.

### 2.7.2 Results

#### Trial 1

At the first sample (after 1.25 l of flow) 30-MS lead concentrations were statistically significantly higher than at stabilisation for total and dissolved lead, for test and control pipes, for both hard and soft waters.

By the end of Trial 1 (after 30 $m^3$ of flow) lead concentrations were not statistically significantly different to concentrations at stabilisation for total and dissolved lead, for test and control pipes, for both hard and soft waters.

[*Note: there was an unexplained disturbance after 5.5 $m^3$ of flow that increased the lead concentrations, particularly the concentration of dissolved lead from the hard water pipes (P1-P4(c)).*]

Additionally, a further test showed that at the first sample (after 1.25 l of flow) the difference between the test and control pipes was not statistically significant for total and dissolved lead, for hard and soft waters (see Figures 2.4 (hard water) and 2.7 (soft water)).

[*Note: the control pipes were temporarily removed from the pipe rig whilst the water meters were installed in the test pipes so as not to be affected by the installation procedure. However, it is believed that the removal of the pipes resulted in sufficient disturbance to cause the initial high lead concentrations observed.*]

## Trial 2

At the first sample (after 1.25 l of flow) adjusted lead concentrations were statistically significantly higher than at stabilisation for total and dissolved lead, for hard and soft waters, for the test pipes. However, for the initial samples taken from the control pipes, the dissolved lead concentrations were significantly higher than at stabilisation (for hard and soft waters), but significantly lower than for the initial samples from the test pipes. In addition, the initial sample from the control pipes for hard and soft waters, had total lead concentrations which were not significantly higher than at stabilisation, but were significantly lower in concentration compared to the test pipes.

Towards the end of Trial 2 (excluding a sample taken after 7.7 $m^3$ of flow), lead concentrations in the test pipes were still higher than at stabilisation. The difference was significant for dissolved lead in hard and soft waters, and for total lead in hard water. The difference was not significant for total lead in soft water.

## Trials 1 and 2 (mean data)

At the end of the initial stabilisation period, mean 30-MS lead concentrations from the test and control pipes were similar for total and dissolved lead, for hard and soft waters, although the concentrations were higher for the hard water than for the soft water.

Trial 1 was characterised by initial large increases in lead concentration from the test and control pipes, for both hard and soft waters, especially for particulate lead. It is likely that the temporary relocation of the control pipes, whilst the meters were installed in the test pipes, was the cause of the increased lead concentrations in the control pipes.

At the end of Trial 1, mean lead concentrations from the test and control pipes were similar for total and dissolved lead, for hard and soft waters. The lead concentrations were higher for the hard water than for the soft water.

Trial 2 saw initial large increases in lead concentrations, particularly particulate lead, from the test pipes and for hard and soft waters; increases from the control pipes were much less.

At the end of Trial 2, total and dissolved lead concentrations from the hard water test pipes were slightly higher than from the control pipe; for the soft water, total lead concentrations from the test pipes were slightly higher than from the control pipe, but dissolved lead concentrations were similar. Again, the lead concentrations were higher for the hard water than for the soft water.

## 2.8 Conclusions

The principal conclusions from Trials 1, 2 and 3:

- Total lead concentrations increased substantially over the 10 µg/l regulatory limit following the installation of water meters in test pipes, irrespective of the degree of disturbance during the installation procedure. The increase in lead concentration was principally due to particulate material.

- In Trial 1, total lead concentrations from the control pipes also increased substantially due to their temporary relocation whilst the water meters were installed in the test pipes. It was noted that some water drained from the pipes during the relocation and it was postulated that the increase in lead was due in part to the turbulence in the pipe when refilled.

- In Trial 2, when the water meter installation procedure created minimal disturbance, increases in total lead concentrations from the control pipes were minimal.

- In Trial 3, total lead concentrations initially increased over the lead standard following refilling of partially drained pipes but decreased to 10 µg/l or less following the passage of up to 293 litres of water (~1,100 pipe volumes). Substantial values were measured for Pipe 6 due to large amounts of particulate matter, possibly emanating from disturbance of sediment or material stripped from the walls of the pipes. Total lead concentrations increased for the hard water pipes as the refilling rate was increased to 12-15 l/min; this trend was not so evident for the soft water, although the highest concentrations were measured at 12-15 l/min. Increases in lead concentrations were largely due to particulate matter.

- A comparison of Trial 1 and Trial 3(b) indicated that physical disturbance during the installation procedure was a major factor responsible for a larger proportion of the increase in total lead (due to particulate material) compared to air/water turbulence. Physical disturbance during their temporary relocation was also a significant factor in the increase in total lead observed for the control pipes in Trial 1.

# 3. Field Trials

Field trials were carried out at consumers' premises. Samples of drinking water were taken before and after installation of water meters into existing lead pipes, and analysed for lead and other key parameters.

The results of the field trials have been compared with the results from the lead pipe rig trials and used as the basis for providing advice to minimise consumer exposure to lead.

## 3.1 Methodology

### 3.1.1 Sampling pre-arranged with customer

Water utilities were asked to identify up to 10 properties where water meters were to be installed in existing lead pipes.

Ideally, a pre-installation visit was planned, to allow WRc to gather information on the property and layout, confirm the presence of a lead supply pipe (if possible), inform the customer with regard to the trial and sampling requirements, provide contact details for WRc and the water utility, and answer any questions. In practice, this was not generally feasible due to logistical considerations.

In all cases, WRc accompanied the meter installer on the day of the meter installation, to witness the installation and take 'Day 0' flushing/post-installation samples.

Labelled bottles and instructions were left with the customer for sampling on 'Day 1' and 'Day 3'. WRc then returned to the property on 'Day 8' to collect the samples taken by the customer and to take a final set of samples.

### 3.1.2 Sampling not pre-arranged with customer

In circumstances where it was not possible to pre-arrange the visit with the customer, WRc accompanied the meter installer in an area identified as likely to include lead service pipes. Where a lead service pipe is identified, WRc asked the customer (if at home) for permission to take pre-installation and 'Day 0' flushing/post-installation samples.

**Table 3.1 Field trial – Summary of analyses planned for samples taken at properties**

| Sample | Day | Sampler | Type | Analysis (ALS) | | | | Analysis & Measurements (WRc) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total lead | Dissolved lead | Phosphate | TOC | Alkalinity | Chlorine | pH | Temp. |
| Pre-installation | - | WRc | RDT | X | X | - | - | - | - | - | - |
| | | | 30-MS | X | X | X | X | X | X | X | X |
| Post-installation | 0 | WRc | Sequential | X | X | - | - | - | - | - | - |
| | | | 30-MS | X | X | X | X | X | X | X | X |
| | 1 | Customer | RDT | X | X | - | - | - | - | - | - |
| | | | 30-MS | X | X | - | - | - | - | - | - |
| | 3 | Customer | RDT | X | X | - | - | - | - | - | - |
| | | | 30-MS | X | X | - | - | - | - | - | - |
| | 8 | WRc | RDT | X | X | - | - | - | - | - | - |
| | | | 30-MS | X | X | X | X | X | X | X | X |

Notes:

1. Pb, $PO_4$, TOC analysed by ALS; alkalinity, Cl (free and total), pH, temperature analysed/measured by WRc.
2. RDT = 1-litre random day time sample; 30-MS = 30 minute stagnation sample; Sequential = samples taken during initial flushing of pipe following meter installation.

## 3.2 Results

### 3.2.1 Property 1 (Western region)

Property 1 was a terraced property built around 1940-1950 and occupied by a 'middle-aged' couple.

An Elster plastic-bodied water meter/EBCO boundary box was installed in the tarmac-covered footpath outside the property on 27th August 2015. The estimated length of lead pipe from the kitchen tap to the water meter was about 14 m; the length of the communication pipe was estimated to be about 4 m.

The tarmac was cut with a petrol-driven rotary cutter and removed. A hole was then dug by hand to a depth of about 1 m to reveal the lead pipe. Access was hampered by the presence of a number of other services: gas, electricity, phone and cable TV (see Photograph 3.1).

**Photograph 3.1 Property 1 - Water meter installation before (left) and after (right) installation of boundary box and water meter**

The existing lead pipe was cut with low pressure shears and the water meter was installed on a 'live' supply from the mains communication pipe. Both sections of the lead pipe, either side of the cut section, were forcibly manipulated to enable the installation of the water meter, and as a result the disturbance to the lead pipe during installation was judged to be high. Whilst connections were made to the communication pipe, water was observed to drain from the customer's supply pipe.

Following completion of the installation (and before reinstatement), WRc flushed[7] the pipe and took samples from the customer's kitchen tap; twenty 1-litre samples were taken at an approximate rate of 8-10 l/min.

Results of the analysis of the pre- and post-installation samples are given in Table 3.2; results of the analysis of the sequential flushed samples are given in Table 3.3. Images of the 0.45 µm membranes used to filter the 125-ml sequential flushed samples (in preparation for dissolved lead analysis) are shown in Photograph 3.2.

## Discussion (Property 1)

Total/dissolved RDT and 30-MS lead concentrations in the pre-installation samples were 1.69/0.95 µg/l and 1.64/1.06 µg/l, respectively; phosphate concentration was 1.39 mg/l as P.

Total/dissolved lead concentrations in the sequential flushed samples peaked at 9,270/21.8 µg/l, respectively, measured in the fourth 1-litre sample. The total lead concentration was approximately a factor of 900 greater than the 10 µg/l lead standard and a factor of up to 90 greater than total lead concentrations of initial flushed samples from Trials 1 and 2.

The total lead concentration, and predominantly the particulate fraction (calculated as 99.8% of the total value), was probably elevated by the forcible manipulation of the lead pipe during the installation procedure.

Total/dissolved lead concentrations in the final flushed sample (20 litres) reduced to 16.0/1.10 µg/l (93.1% particulate), remaining higher than the total lead standard. Total/dissolved lead concentrations (32.3/16.0 µg/l (50.5% particulate)) increased in the 30-MS samples taken following flushing, due principally to the increase in dissolved lead.

Total lead concentrations in RDT samples taken on Day 1 (2.72 µg/l) after an estimated flow of 407 litres, and thereafter, complied with the regulatory limit for lead.

It was observed that the change in colour of the flushed samples generally correlated with the change in lead concentrations as indicated by the values in Table 3.3 and the used membrane filters shown in Photograph 3.2.

[7] Water company literature given to the customer by the contractor advised flushing for 2-3 minutes.

**Table 3.2 Field trial – Pre and post-installation water analysis (Property 1)**

| Date / sample | Vol. water[1] | $PO_4$ | RDT lead | | 30-MS lead | | pH | Temp. | TOC | Total alkalinity | Free chlorine | Total chlorine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Litres | mgP/l | Total µg/l | Dissolved µg/l | Total µg/l | Dissolved µg/l | | °C | mgC/l | $mgCaCO_3/l$ | $mgCl_2/l$ | $mgCl_2/l$ |
| 24/08 Pre-sample | - | 1.39 | 1.69 | 0.95 | 1.64 | 1.06 | 7.44 | 13.0 | 1.50 | - | 0.02 | 0.12 |
| 27/08 Day 0[2] | 20 | 1.41 | - | - | 32.3 | 16.0 | 7.28 | 16.5 | 1.40 | 103 | 0.03 | 0.13 |
| 28/08 Day 1 | (407) | - | 2.72 | 0.78 | 2.74 | 0.86 | - | - | - | - | - | - |
| 30/08 Day 3 | (1,181) | - | 2.30 | 0.80 | 4.57 | 2.51 | - | - | - | - | - | - |
| 04/09 Day 8 | 3,117 | 1.47 | 5.69 | 0.95 | 4.01 | 0.76 | 7.40 | 17.8 | 1.70 | 153 | 0.10 | 0.12 |

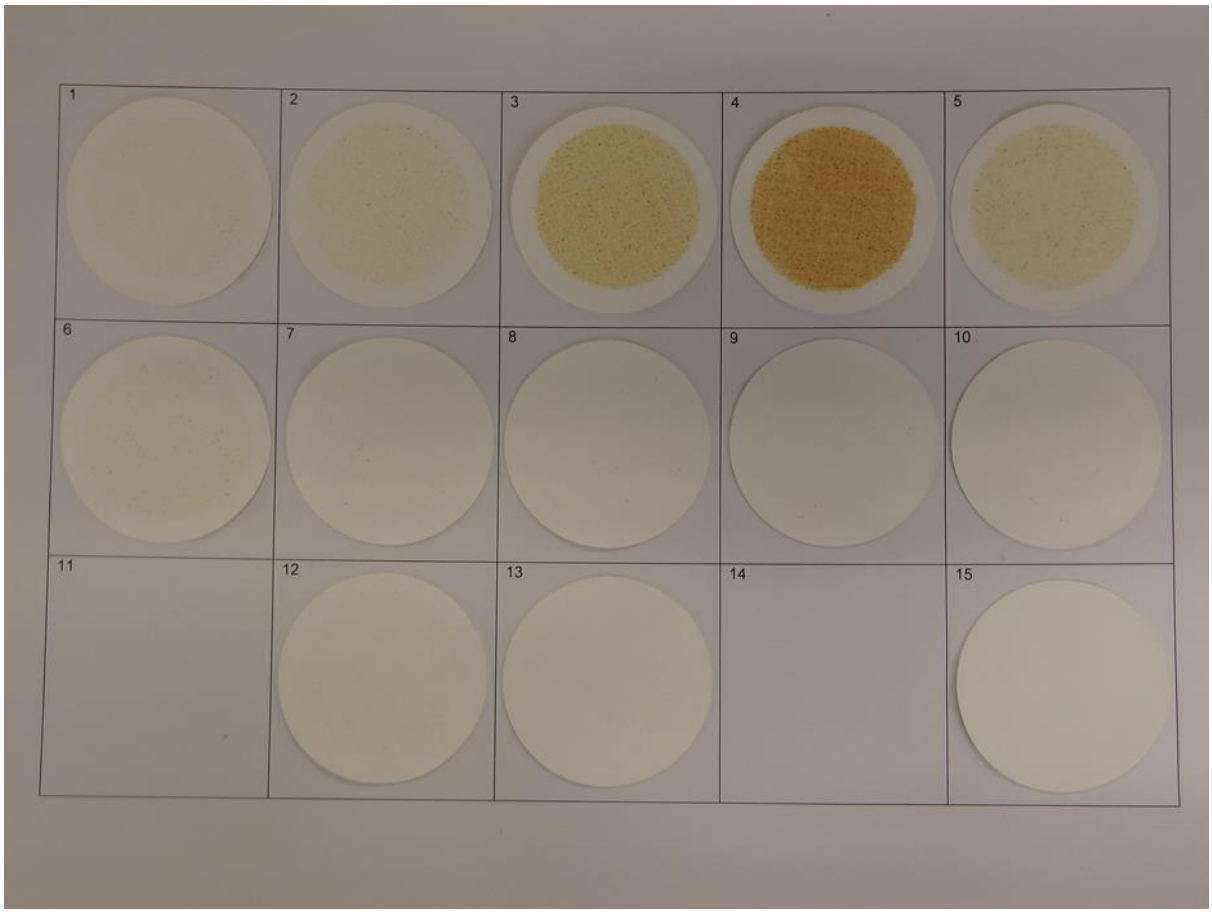
Notes:

1. Day 0 and Day 8 values as indicated on the water meter; Day 1 and Day 3 values estimated.
2. Day 0 30-MS sample taken after completion of flushing.

**Table 3.3 Field trial - Lead concentration in flushed samples following meter installation (Property 1)**

| Date / sample | Vol. water | Total lead | Dissolved lead | Apparent colour |
|---|---|---|---|---|
| | Litres | µg/l | µg/l | °Hazen |
| 27/08 Day 0(a) | 1 | 441 | 3.43 | 7.9 |
| 27/08 Day 0(b) | 2 | 1330 | 4.78 | 15.4 |
| 27/08 Day 0(c) | 3 | 5230 | 7.75 | 55.8 |
| 27/08 Day 0(d) | 4 | 9270 | 21.8 | 140.8 |
| 27/08 Day 0(e) | 5 | 2920 | 7.21 | 40.7 |
| 27/08 Day 0(f) | 6 | 355 | 4.80 | 12.0 |
| 27/08 Day 0(g) | 7 | 172 | 3.91 | 4.9 |
| 27/08 Day 0(h) | 8 | 118 | 2.46 | 4.4 |
| 27/08 Day 0(i) | 9 | 103 | 2.33 | 4.9 |
| 27/08 Day 0(j) | 10 | 77.1 | 1.91 | 3.3 |
| 27/08 Day 0(k) | 15 | 103 | 1.36 | 3.6 |
| 27/08 Day 0(l) | 20 | 16 | 1.10 | 2.6 |

**Photograph 3.2 Field trial - Membrane filters after filtration of 125-ml flushed samples (Property 1)**




**(Key: '1'-'10' = 1–10 litres flushed; '12' = 15 litres flushed; '13' = 20 litres flushed; '15' = drinking water)**

### 3.2.2 Property 2 (Central and Eastern region)

Property 2 was a semi-detached property built around the 1930s and occupied by a 'middle-aged' couple. The mains water was further treated within the property by ion exchange and reverse osmosis; the supply to the drinking water tap in the kitchen was remineralised. Because of this arrangement, mains water samples were taken from the garden tap, without the additional treatment.

An Elster plastic-bodied water meter/ATPLAS boundary box was installed in the tarmac-covered footpath outside the property on 3rd March 2016. The estimated length of lead pipe from the garden tap to the water meter was 22 m; the length of the communication pipe was estimated to be 4 m.

The tarmac was cut with a pneumatic reciprocating breaker and removed. A hole was then dug by hand to a depth of about 0.75 m to reveal the lead pipe. The hole was free of

obstructions and the stop tap was located in a straight section of lead pipe (see Photograph 3.3).

**Photograph 3.3 Excavated lead pipe with isolating tap before installation of water meter (Property 1)**

The existing lead pipe was cut with low pressure shears and the water meter was installed on a 'live' supply from the mains communication pipe. The disturbance to the lead pipe during installation was judged to be low-to-medium. Whilst connections were made to the communication pipe, water was observed to drain from the customer's supply pipe.

Following completion of the installation (and during reinstatement), WRc flushed[8] the pipe and took samples from the customer's garden tap. The first 20 litres was sampled, with separate 1-litre samples taken at an approximate rate of 8-12 l/min, followed by 1-litre samples taken after 25 litres, 30 litres, 35 litres, 40 litres and 50 litres.

Results of the analysis of the pre- and post-installation samples are given in Table 3.2; results of the analysis of the sequential flushed samples are given in Table 3.3.

[8] Water company literature given to the customer by the contractor advised flushing for 2-3 minutes.

## Discussion (Property 2)

The concentration of total and dissolved lead in the pre-installation RDT sample measured 1.84 and 1.36 µg/l respectively; phosphate concentration was 1.44 mg/l as P.

The concentration of total and dissolved lead in the sequentially flushed samples peaked at 1,060 and 18.1 µg/l, respectively, measured in the ninth 1-litre sample. The total lead concentration was approximately a factor of 100 greater than the 10 µg/l lead standard and a factor of up to 10 greater than the lead concentration in the initial flushed samples from pipe rig trials (1 and 2).

Particulate lead was 98.3% of the total value, comparable to the value from Property 1 although the total value was significantly less, possibly due to the lesser degree of disturbance of the lead pipe during the installation procedure.

The concentration of total lead in the final flushed sample (50 litres) had reduced to 27.0 µg/l, remaining higher than the lead standard. It was observed that the apparent colour of the flushed samples generally correlated with the measured lead concentration, as indicated by the values in Table 3.3.

Samples were not taken by the householder subsequent to the visit.

**Table 3.4 Field trial - Pre and post-installation water analysis (Property 2)**

| Date / sample | Vol water[1] | $PO_4$ | RDT lead | | 30-MS lead | | pH | Temp | TOC | Total alkalinity | Free chlorine | Total chlorine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Litres | mgP/l | Total µg/l | Dissolved µg/l | Total µg/l | Dissolved µg/l | | °C | mgC/l | $mgCaCO_3/l$ | $mgCl_2/l$ | $mgCl_2/l$ |
| Pre-installation: 03/03/16 Day 0 | - | 1.44 | 1.84 | 1.36 | - | - | 7.84 | 7.8 | 0.60 | 223 | 0.02 | 0.02 |
| Post-installation: 03/03/16 Day 0 | 50 | 2.96 | - | - | - | - | 7.68 | 7.8 | 0.70 | 240 | 0.22 | 0.36 |

Notes:

1. Day 0 pre-installation sample taken before any disturbance to the supply.
2. Day 0 post-installation sample taken after installation and reinstatement, after 50 litres of flushing.

**Table 3.5 Field trial - Lead concentration in flushed samples (Property 2)**

| Date / sample | Vol. water | Total lead | Dissolved lead | Apparent colour |
|---|---|---|---|---|
| | Litres | ug/l | ug/l | °Hazen |
| 03/03 Day 0(a) | 1 | 3.81 | 6.8 | 1.82 |
| 03/03 Day 0(b) | 3 | 5.03 | 3.16 | 1.82 |
| 03/03 Day 0(c) | 5 | 4.52 | 4.89 | 2.34 |
| 03/03 Day 0(d) | 7 | 489 | 7.6 | 24.2 |
| 03/03 Day 0(e) | 9 | 1060 | 18.1 | 30.4 |
| 03/03 Day 0(f) | 11 | 532 | 16.3 | 37.4 |
| 03/03 Day 0(g) | 13 | 236 | 9.88 | 28.3 |
| 03/03 Day 0(h) | 15 | 91 | 3.78 | 21.1 |
| 03/03 Day 0(i) | 17 | 190 | 2.9 | 23.4 |
| 03/03 Day 0(j) | 19 | 111 | 2.11 | 19.0 |
| 03/03 Day 0(k) | 20 | 178 | 2.25 | 16.9 |
| 03/03 Day 0(l) | 25 | 71.3 | 1.88 | 10.9 |
| 03/03 Day 0(m) | 30 | 62.5 | 1.70 | 12.5 |
| 03/03 Day 0(n) | 35 | 11.0 | 1.32 | 8.58 |
| 03/03 Day 0(p) | 40 | 21.6 | 1.33 | 9.62 |
| 03/03 Day 0(q) | 50 | 27.1 | 1.31 | 8.58 |

### 3.2.3 Property 3 (London & South-East region)

Property 3 was a semi-detached house built in 1956 and occupied by an ‘elderly’ couple. The communication pipe was confirmed as lead, terminating at an external stop valve, approximately 3 m from the centre line of the road. The chamber housing the external stop valve was located underneath a concrete driveway, and the valve itself was supported underneath by a concrete plinth.

The customer supply pipe was confirmed as lead, approximately 12 mm ID and 15 m long, terminating at an internal stop valve in the downstairs toilet, within the house.

#### Meter installation procedure

A pneumatic tool was used to break up an area of concrete around the existing chamber. The broken concrete was removed using hand tools, and the underlying earth dug out using a spade. The external stop valve was closed and the customer supply pipe cut through using a

hand tool (ratchet type pipe cutting tool). The cut pipe was disinfected with sodium hypochlorite spray and a 'plastic to lead' connector was then fitted to the customer supply pipe.

The upstream pipe and existing stop valve were lifted and bent back by 90°, to allow the concrete plinth to be removed. This was necessary to accommodate the new Elster 'AJUSTA' boundary box. The upstream pipe was then cut through whilst 'live' using a hand tool (ratchet type pipe cutting tool) and the existing stop valve removed.

The new boundary box was then fitted, and an Elster water meter installed. Finally, the soil was refilled into the hole, with some compaction using a heavy hand tool. The surface made up with cold fill tarmac as a temporary repair, again compacted by hand tool, until a repair with concrete was made. Overall, the disturbance to the pipe was judged to be medium to high, due to the bending of the pipe to remove the concrete plinth.

## Customer advice

The occupants of the property were given an information card by the contractors, produced by the Water Company. This recommended that '*before using your kitchen tap you flush it for about 1 minute to remove any harmless residual chlorine or particles'*. The same recommendation was also made for an outside tap. Additionally, the advice recommended that the occupants should '*run your kitchen tap for a short time every day for about a month before using it for drinking or cooking, especially if the tap has not been used for a long time. This will allow time for the protective layer on the inside of the pipe to re-establish*'.

## Sampling on day of meter installation (Day 0)

Before commencement of the meter installation works, samples of water were taken by WRc from the cold water supply in the kitchen, adjacent to the downstairs toilet. These were analysed immediately for water temperature, and free / total chlorine concentration. Further analyses were carried out at WRc (Total alkalinity, total hardness, pH) and by ALS (Total and dissolved lead, TOC, phosphate).

Following completion of the installation, sequential volumes of 1 litre each were collected from the cold water supply tap for the first 20 litres, at a flow rate of approximately 6 l/min, with alternate samples being retained for lead analysis. Some air was displaced from the pipe during this process.

Further 1 litre samples were taken, with retention for lead analysis at increasing intervals. Finally a 1 litre sample was taken for lead analysis after approximately 100 litres had been flushed through, and a further 1 litre used to fill a commercial available water filter. The filter is intended to treat 1 litre batches of water and contained a mixture of ion-exchange resins and granular activated carbon. The filter is designed to reduce the concentration of chlorine, water hardness and heavy metals. The filtrate from the water filter was retained for lead analysis.

## Sampling on days after meter installation (Days 1, 3 and 8)

Further 1 litre samples were taken by the occupants of the property on Days 1 and 3, at an unspecified time (random, but not first draw) from the cold water supply in the kitchen. Following these random day time samples, further 30 minute stagnation samples were taken by the occupants.

On Day 8, WRc took a further random day time sample and a 30 minute stagnation sample. The water meter reading was recorded from the newly installed meter.

## Water quality measurements

The water quality during the sampling exercise at property 3 is summarised in Table 3.6 and Table 3.7.

**Table 3.6 Filed trial – Pre and post-installation water analysis (Property 3)**

| Date / sample | Vol. water | $PO_4$ | RDT lead | | 30-MS lead | | pH | Temp | TOC | Total alkalinity | Free chlorine | Total chlorine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Litres | mgP/l | Total µg/l | Dissolved µg/l | Total µg/l | Dissolved µg/l | | °C | mgC/l | $mgCaCO_3/l$ | $mgCl_2/l$ | $mgCl_2/l$ |
| Pre-installation: 12/04/16 Day 0[1] | - | 1.02 | 2.84 | 1.29 | - | - | 7.21 | 10.8 | 0.1 | 204 | <0.05 | 0.14 |
| Post-installation: 13/04/2016 Day 1 | 280[2] | - | 16.2 | 4.19 | 2.44 | 2.37 | - | - | - | - | - | - |
| Post-installation: 15/04/2016 Day 3 | 645[2] | - | 2.60 | 1.89 | 1.94 | 1.85 | - | - | - | - | - | - |
| Post-installation: 20/04/2016 Day 8 | 1546 | 0.83 | 2.97 | 2.26 | 2.57 | 2.36 | 7.08 | 19.7 | 0.4 | 208 | <0.05 | 0.18 |

Notes

1. Prior to any disturbance caused by preparations to install meter.
2. Estimate based on final meter reading on Day 8.

**Table 3.7 Field trial - Lead concentration in flushed samples (Property 3)**

| Date / sample | Vol. water | Total lead | Dissolved lead | Apparent colour |
|---|---|---|---|---|
| | Litres | ugPb/l | ugPb/l | °Hazen |
| 12/04 Day 0(a) | 1 | 6.17 | 4.80 | 0.5 |
| 12/04 Day 0(b) | 3 | 329.0 | 3.79 | 20.5 |
| 12/04 Day 0(c) | 5 | 573.0 | 4.10 | 36.1 |
| 12/04 Day 0(d) | 7 | 107.0 | 3.55 | 7.7 |
| 12/04 Day 0(e) | 9 | 45.1 | 2.73 | 4.6 |
| 12/04 Day 0(f) | 11 | 16.0 | 2.47 | 1.0 |
| 12/04 Day 0(g) | 13 | 9.45 | 2.20 | 1.0 |
| 12/04 Day 0(h) | 15 | 5.22 | 2.45 | <1 |
| 12/04 Day 0(i) | 17 | 2.39 | 1.89 | <1 |
| 12/04 Day 0(j) | 19 | 3.13 | 1.63 | <1 |
| 12/04 Day 0(k) | 20 | 2.20 | 1.43 | <1 |
| 12/04 Day 0(l) | 25 | 1.59 | 1.17 | <1 |
| 12/04 Day 0(m) | 30 | 1.80 | 1.59 | <1 |
| 12/04 Day 0(n) | 35 | 2.68 | 1.27 | <1 |
| 12/04 Day 0(p) | 40 | 1.87 | 1.18 | <1 |
| 12/04 Day 0(q) | 50 | 1.97 | 1.32 | <1 |
| 12/04 Day 0(r) | 100 | 9.48 | 2.45 | <1 |
| 12/04 Day 0(s) | 100[WF] | 1.65 | 1.25 | 3.1 |
| 13/04 Day 1 RDT | 280* | 16.2 | 4.19 | - |
| 15/04 Day 3 RDT | 645* | 2.60 | 1.89 | - |
| 20/04 Day 8 RDT | 1546 | 2.97 | 2.26 | - |

**Notes**

WF: Sample treated with commercially available water filter.

*Estimated from final meter reading on Day 8

## Discussion (Property 3)

The concentration of total lead in the pre-installation RDT sample was 2.84 µg/l; phosphate concentration was 1.02 mg/l as P.

Despite the manipulation of the lead pipe during installation of the meter, to enable removal of the concrete plinth underneath, the maximum total concentration of lead following meter

installation was significantly less than that measured at Property 1 and 2. The concentration of total lead in the sequentially flushed samples peaked at 573 µg/l, measured in the fifth 1-litre sample. However, it is possible that the peak concentration was greater, if it occurred in 4$^{th}$ or 6$^{th}$ litre portions of flushed water, as these were not analysed. The total lead concentration had reduced below the regulatory limit after a total of 13 litres had been flushed through.

At its greatest concentration, particulate lead was 99.3% of the total value, comparable to the value from Properties 1 and 2. The use of a commercial water filter appeared to be effective, reducing the total lead concentration from 9.48 µg/l to 1.65 µg/l in the 100 litre post flush sample.

The concentration of dissolved lead increased from 1.29 µg/l in the pre-installation RDT sample to a maximum of 4.8 µg/l, measured in the first 1 litre sample of flushed water.

The apparent colour of the flushed samples generally correlated with the measured total lead concentration.

The total lead concentration in the RDT sample on Day 1, taken by the householder, exceeded the prescribed maximum, whilst the 30-MS sample on the same day was well below this standard, suggesting that the RDT sample had been stagnant for significantly longer than 30 minutes.

The total lead concentration in the RDT samples on Day 3 and 8 were well below the prescribed maximum.

### 3.2.4 Property 4 (London & South-East region)

Property 4 was a semi-detached house built in 1934 and occupied by a single 'elderly' man. The communication pipe was confirmed as lead, terminating at an external stop valve, approximately 3 m from the centre line of the road. The chamber housing the external stop valve was located in the tarmac pavement outside the property.

The customer supply pipe was confirmed as lead, approximately 12 mm ID and 14 m long, terminating at an internal stop valve in the kitchen.

#### Meter installation procedure

A pneumatic tool was used to break up an area of concrete around the existing chamber. The broken concrete was removed using hand tools, and the underlying earth dug out using a spade. The external stop valve was closed and the customer supply pipe cut through using a hand tool (ratchet type pipe cutting tool). The cut pipe was disinfected with sodium hypochlorite spray and a 'plastic to lead' connector was then fitted to the customer supply pipe.

The supply pipe was first cut-through on the isolated side of the existing stop tap, and then cut through on the 'live' side, using a hand tool (ratchet type pipe cutting tool). The existing stop valve was then removed and a new Elster 'AJUSTA' boundary box was installed. An Elster water meter was fitted into the boundary box and the supply isolating valve opened. Finally, the soil was refilled into the hole, with some compaction using a heavy hand tool. The surface made up with cold fill tarmac, again compacted by hand tool. Overall, the disturbance to the pipe was judged to be low to medium.

#### Customer advice

The occupants of the property were given an information card by the contractors, produced by the Water Company. This recommended that '*before using your kitchen tap you flush it for about 1 minute to remove any harmless residual chlorine or particles'*. The same recommendation was also made for an outside tap. Additionally, the advice recommended that the occupants should '*run your kitchen tap for a short time every day for about a month before using it for drinking or cooking, especially if the tap has not been used for a long time. This will allow time for the protective layer on the inside of the pipe to re-establish*'.

#### Sampling on day of meter installation (Day 0)

Before commencement of the meter installation works, samples of water were taken by WRc from the cold water supply in the kitchen. These were analysed immediately for water temperature, and free / total chlorine concentration.

Further analyses were carried out at WRc (Total alkalinity, total hardness, pH) and by ALS (Total and dissolved lead, TOC, phosphate).

Following completion of the installation, sequential volumes of 1 litre each were collected from the cold water supply tap for the first 20 litres, at a flow rate of approximately 6 l/min, with alternate samples being retained for lead analysis. Some air was displaced from the pipe during this process.

Further 1 litre samples were taken, with retention for lead analysis at increasing intervals. Finally a 1 litre sample was taken for lead analysis after approximately 100 litres had been flushed through, and a further 1 litre used to fill a commercially available jug water filter. The filter is intended to treat 1 litre batches of water and contained a mixture of ion-exchange resins and granular activated carbon. The filter is designed to reduce the concentration of chlorine, water hardness and heavy metals. The filtrate from the water filter was retained for lead analysis.

## Sampling on days after meter installation (Days 1, 3 and 8)

Further 1 litre samples were taken by the occupants of the property on Days 1 and 3, at an unspecified time (random, but not first draw) from the cold water supply in the kitchen. Following these random day time samples, further 30 minute stagnation samples were taken by the occupants.

On Day 8, WRc took a further random day time sample and a 30 minute stagnation sample. The water meter reading was recorded from the newly installed meter.

## Water quality measurements

The water quality during the sampling exercise at property 4 is summarised in Table 3.6 and Table 3.9.

**Table 3.8 Field trial - Pre and post-installation water analysis (Property 4)**

| Date / sample | Vol. water | $PO_4$ | RDT lead | | 30-MS lead | | pH | Temp | TOC | Total alkalinity | Free chlorine | Total chlorine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Litres | mgP/l | Total µg/l | Dissolved µg/l | Total µg/l | Dissolved µg/l | | °C | mgC/l | $mgCaCO_3/l$ | $mgCl_2/l$ | $mgCl_2/l$ |
| Pre-installation: 12/04/16 Day 0[1] | - | 0.934 | 4.58 | 5.83 | - | - | 6.70 | 12.2 | 0.3 | 110 | 0.02 | 0.19 |
| Post-installation: 13/04/2016 Day 1 | 206[2] | - | 2.77 | 2.29 | 4.18 | 3.06 | - | - | - | - | - | - |
| Post-installation: 15/04/2016 Day 3 | 418[2] | - | 3.93 | 3.08 | 7.14 | 5.57 | - | - | - | - | - | - |
| Post-installation: 20/04/2016 Day 8 | 947 | 0.926 | 5.80 | 4.96 | 4.73 | 4.46 | 7.28 | 12.4 | 0.6 | 110 | 0.07 | 0.27 |

Notes

1. Prior to any disturbance caused by preparations to install meter.
2. Estimate based on final meter reading on Day 8.

**Table 3.9 Field trial - Lead concentration in flushed samples (Property 4)**

| Date / sample | Vol. water | Total lead | Dissolved lead | Apparent colour |
|---|---|---|---|---|
| | Litres | ug/l | ug/l | °Hazen |
| 12/04 Day 0(a) | 1 | 12.7 | 5.85 | 0.8 |
| 12/04 Day 0(b) | 2 | 2400 | 14.90 | 214 |
| 12/04 Day 0(c) | 4 | 123 | 6.36 | 3.8 |
| 12/04 Day 0(d) | 6 | 22.5 | 4.20 | 1.3 |
| 12/04 Day 0(e) | 8 | 75.1 | 3.68 | 1.5 |
| 12/04 Day 0(f) | 10 | 29.3 | 3.49 | 1.0 |
| 12/04 Day 0(g) | 12 | 139 | 3.45 | 2.0 |
| 12/04 Day 0(h) | 14 | 24.1 | 3.14 | 1.3 |
| 12/04 Day 0(i) | 16 | 19.9 | 2.58 | 0.8 |
| 12/04 Day 0(j) | 18 | 6.05 | 2.79 | 0.5 |
| 12/04 Day 0(k) | 20 | 14.5 | 2.79 | 0.8 |
| 12/04 Day 0(l) | 25 | 20.7 | 2.49 | 0.5 |
| 12/04 Day 0(m) | 30 | 7.33 | 2.61 | 1.3 |
| 12/04 Day 0(n) | 35 | 4.22 | 2.72 | 0.3 |
| 12/04 Day 0(p) | 40 | 37.0 | 2.93 | 1.0 |
| 12/04 Day 0(q) | 50 | 75.6 | 3.18 | 1.0 |
| 12/04 Day 0(r) | 100 | 4.24 | 2.69 | 2.3 |
| 12/04 Day 0(s) | 100[WF] | 1.13 | 1.24 | 10.8 |
| 13/04 Day 1 RDT | 206** | 2.77 | 2.29 | - |
| 15/04 Day 3 RDT | 418** | 3.93 | 3.08 | - |
| 20/04 Day 8 RDT | 947 | 5.80 | 4.96 | - |

**Notes**

*Observed as peak discolouration

WF: Sample treated with commercial jug water filter

**Estimated from final meter reading on Day 8

## Discussion (Property 4)

The concentration of total lead in the pre-installation RDT sample was 4.58 µg/l; phosphate concentration was 0.93 mg/l as P. The measured concentration of dissolved lead was slightly greater than the total, but this is presumed to be due to analytical variation.

Following installation of the water meter, the concentration of total lead in the sequentially flushed samples peaked at 2400 µg/l, measured in the second 1-litre sample. This was visually observed to coincide with the peak in apparent colour. During flushing, the change in total lead concentration was somewhat erratic, reducing to below the prescribed maximum after a total of 18 litres had been flushed through, but subsequently increasing to a maximum of 76 µg/l (50 litres flushed), before reaching a minimum of 4.2 µg/l after 100 litres had been flushed. The reason for the erratic changes in concentration are not known.

The use of a commercial jug water filter appears to have been effective, reducing the total lead concentration from 4.24 µg/l to 1.13 µg/l in the 100 litre post flush sample.

The concentration of dissolved lead increased from 5.8 µg/l in the pre-installation RDT sample to a maximum of 14.9 µg/l, measured in the second 1 litre sample of flushed water. Dissolved lead remained below the regulatory standard for the remainder of the monitoring on Day 0.

The apparent colour of the flushed samples generally correlated with the measured total lead concentration.

The total lead concentration in the RDT and 30-MS samples on Days 1, 3 and 8, remained less than the regulatory limit.

# 4. Conclusions

The overarching conclusion form this study is that installation of meters or other fittings into lead pipes can lead to transient increases in lead concentration in the water. These elevated concentrations, mainly of particulate lead, can last for about 3 days and can be effectively removed by flushing.

## 4.1 Pipe rig trials

- Total lead concentration in drinking water increased to a concentration substantially greater than the regulatory standard (10 µg/l) following the installation of water meters in test pipes. Values of up to 278 µg/l in first flush samples and 419 µg/l in 30-MS samples were recorded for tests without induced air disturbance. Values of up to 612 µg/l in first flush samples and 286 µg/l in 30-MS samples were recorded in tests with induced air disturbance.

- The increase in lead concentration was principally due to particulate material.

- The increase in lead concentration was reduced substantially by flushing, and total and dissolved lead concentrations were reduced to approximate pre-installation values (<10 µg/l) after the passage of 900-2,700 litres of water, equivalent to 3-9 days of typical domestic water use for a household of 2 people.

## 4.2 Field trials

- Installation of a water meter to old lead supply pipes resulted in a subsequent temporary increase in the concentration of total lead in the water supply. The degree of increase varied substantially between the sites monitored, peaking at between 573 and 9,700 µg/l. The observed increases were markedly greater than those observed in the controlled pipe rig tests. The reasons for this are most probably a combination of the age of the lead pipes in the field study, with associated accumulations of lead compounds on the pipe wall, together with the greater disturbance as a result of manual manipulation of pipes in the process of meter installation.

- The degree of increase in total lead concentration did not to appear to be consistently related to the degree of pipe disturbance, indicating that other factors were also important.

- The concentration of dissolved lead also increased subsequent to the meter installation, but to a far lesser degree, peaking at between 5 and 22 µg/l.

- For the 2 sites where a 100 litre flush was applied on Day 0, total lead concentration measured less than 10 µg/l in the final samples taken on Day 0.

- The total concentration of lead remained at less than 10 µg/l in both the RDT and 30-MS samples taken on Days 1, 3 and 8 after meter installation, at the 3 properties where this was measured, with a single sample exception. This represented a volume of between 200 and 400 litres used between meter fitting on Day 0 and sampling on Day 1.

- Flushing of the water supply to waste immediately following installation of a water meter into an old lead supply pipe is clearly an effective method of reducing the potential for customer exposure to elevated concentration of lead. The flushing requirement will depend upon a range of factors:

  – Internal pipe condition
  – Degree of manipulation of the pipe during installation
  – Degree of disturbance during repairs to the ground around the newly installed boundary box
  – Length of the supply pipe.

- Very limited tests using a proprietary jug type water filter indicated that this could be an effective additional temporary measure, in the week following the installation, to further reduce the total and dissolved concentration of lead in water.

# 5. Suggestions

## 5.1 Post installation flushing regime

Where the installer determines that the service pipe is lead, the consumer should be informed of this fact and offered the standard company advice on lead pipes. In addition they should be advised to flush their cold water supply immediately following the installation, for a minimum of 10 minutes, and to flush again for 2 minutes at the first use of the kitchen tap, for the next 3 days.

# Appendix A Lead pipe test rig

## A1 Design

A lead pipe test rig was designed and built to investigate the effects of the installation of water fittings on drinking water quality (Figure A.1).

The test rig incorporated eight streams consisting of 3.0 m sections of new lead pipe (nominal bore 12.7 mm) with appropriate pumping, flow control and sampling. Initial trials were carried out on soft and hard phosphate-dosed waters: four pipes were contacted with the soft water and four pipes with the hard water. Each bank of four pipes comprised 3 test pipes and 1 control pipe.

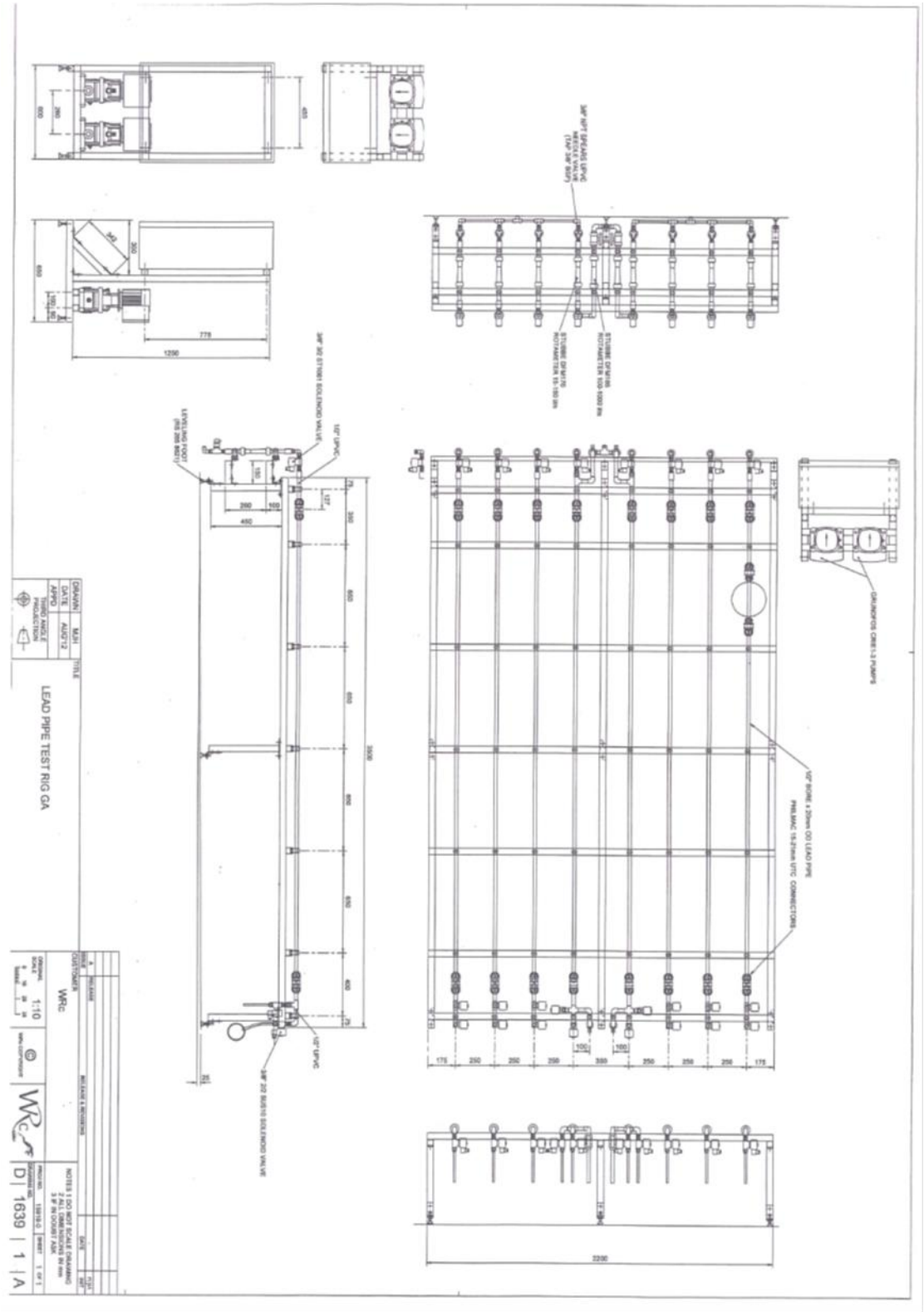
The pipes each provided a stagnation sample volume of 385 ml. Apart from the pipework and fittings to be tested, all other water-contact components used on the test rig were lead-free WRAS approved fittings and materials. The rig was fitted with timer-controlled solenoid valves to allow defined (and realistic) durations of stagnation and flow to be applied. Each section of pipe was fitted with a manual flow control and flow meter (40-400 l/h).

The lead pipe rig was designed to replicate mean flows through a lead pipe, with a diurnal pattern incorporating periods of stagnation and flow. The flow rate selected for the initial trials was 360 l/h (6 l/min) based on:

- The minimum regulatory flow capability to a property is 9 l/min.
- 'Identiflow' water usage to single properties indicated typical peak flows of about 5-9 l/min. The majority of peaks were below 4-8 l/min; higher peaks were recorded probably indicating simultaneous water usage where only a proportion of flow would be attributed to the kitchen tap.
- *Ad hoc* tests filling a kitchen appliance indicated typical peak flows of about 8-10 l/min.
- Hayes *et al*. (2010)[9] indicate normal sampling flow rates in practice of about 6 l/min.
- Turbulent flow conditions (Re=3000) in a 12.7-mm pipe (promoting particulate pick-up and plug flow conditions) will occur at about v = 0.24 m/s (equivalent to 0.03 l/s, 1.8 l/min, 109 l/h).

[9] Hayes *et al.* (2010). Best Practice Guide on the Control of Lead in Drinking Water.

**Figure A.1 Lead pipe test rig (general arrangement)**



## A2 Operation

### A2.1 Specification of flow regime

Flows to single properties are characterised by intermittent peaks of short duration, typically occurring 2-3 times per hour, with one (or more) longer period(s) of stagnation indicating night time sleep or periods when a property is unoccupied. Two examples of flow patterns to single properties are shown in Figures A.2 and A.3, derived from high resolution flow monitoring exercises by WRc at residential properties.

**Figure A.2 Flow to property: Two occupants (some daytime occupancy)**

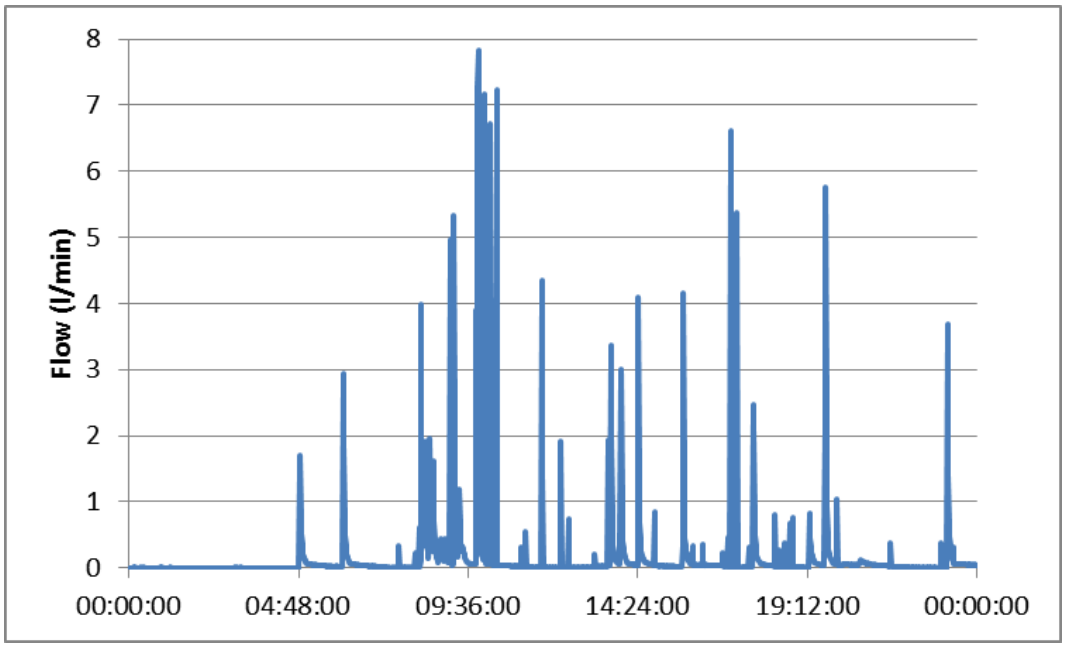
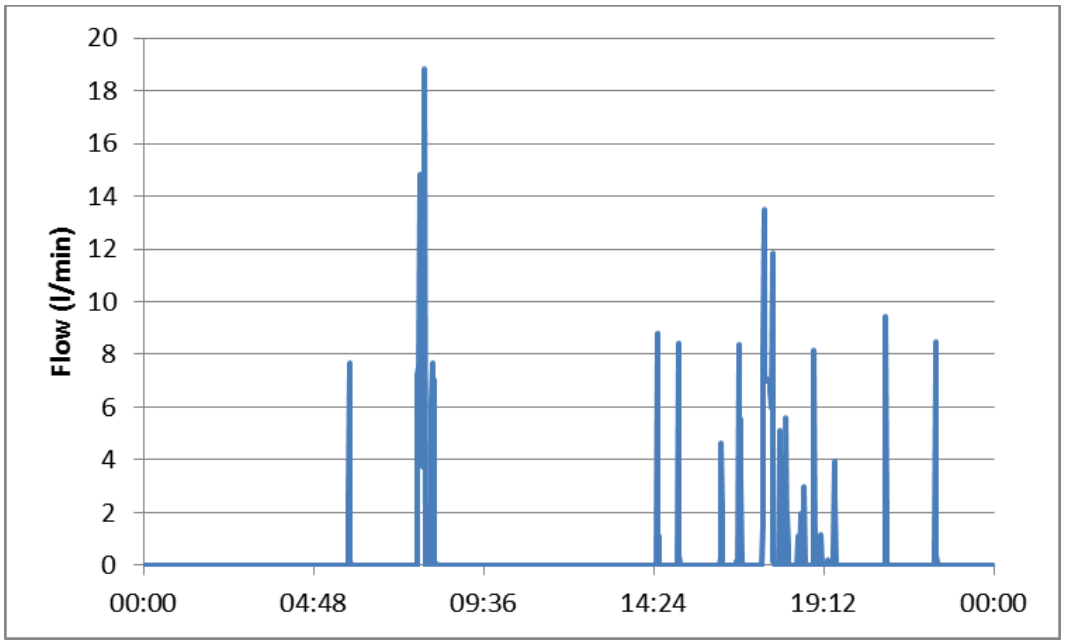
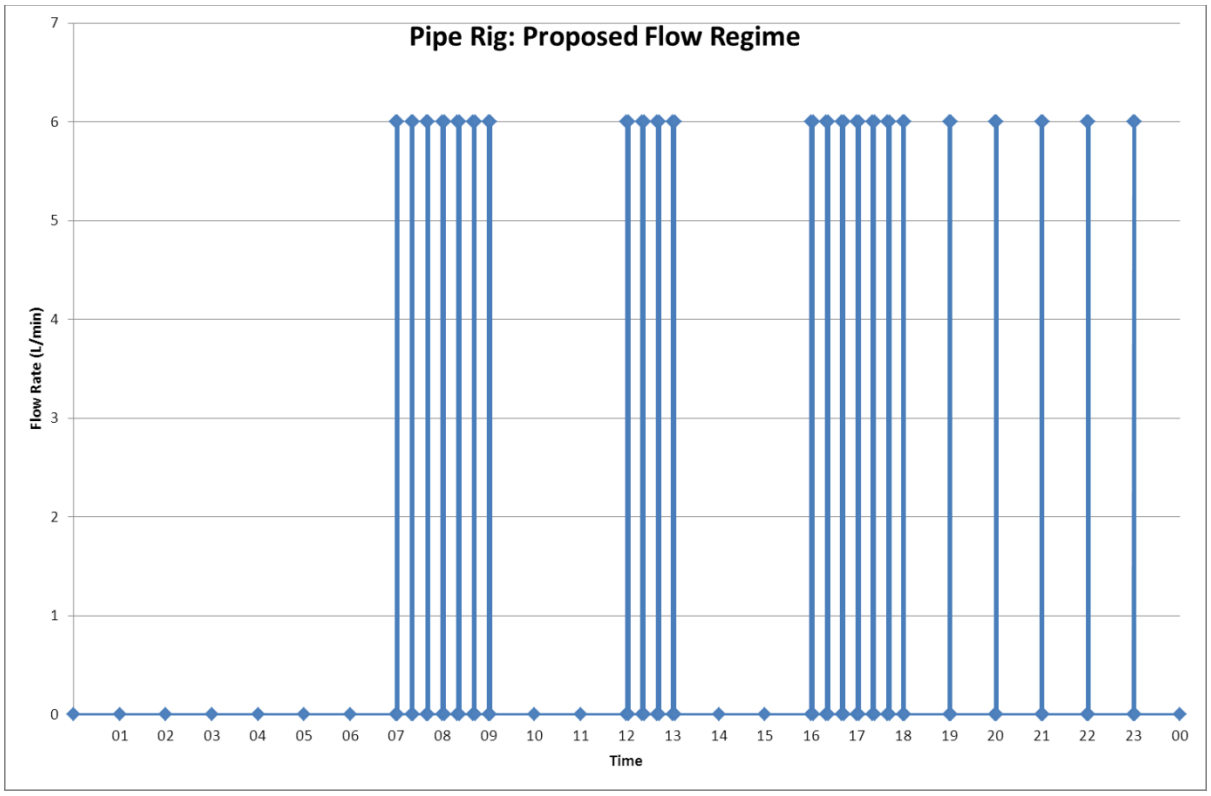


**Figure A.3 Flow to property: Two occupants (no daytime occupancy)**




Following discussion with DWI, it was agreed to implement a flow regime to each pipe that replicated flow to a single property unoccupied for two periods during the day, with flows at 6 l/min for periods of 2 or 3 min, and a total daily flow of 360 l/d (based on 2.4 persons x 150 l/person.d) (see Figure A.4).

**Figure A.4 Pipe rig flow regime**




### i) Sampling

All samples from the pipe rig (30-minute stagnation (30-MS), grab and first-draw) were taken at 6 l/min.

The volume of a 3.0 m 11-mm internal diameter pipe is 285 ml[10]. During 30-MS sampling, only water contained within the pipe should be sampled (as larger volumes will dilute the concentration of lead). To ensure that appropriate volumes were sampled, the sampling period was set at 2.5 seconds, equivalent to a sample volume of about 220 ml.

### ii) Chemical analysis

Chemical analysis was carried out by ALS Environmental (formerly STS Analytical Services) for lead (total and dissolved), TOC (total organic carbon) and orthophosphate.

The following parameters were measured at WRc: pH, $UV_{254}$ absorbance, colour, chlorine, alkalinity, hardness, and water temperature. Water temperature was measured continuously with data logged using a Squirrel datalogger.

[10] Initial calculations assumed a nominal 12.7-mm internal bore and corresponding volume of 380 ml.

## A2.2 Sources of water

### A2.2.1 Hard water

The hard water used in the trials was Swindon tap water. Water was delivered to a 0.6 $m^3$ black polythene feed tank, with the flow controlled by a brass-bodied float valve.

Initially the water was pumped as delivered. However, in mid-February 2013 it was agreed with DWI to implement supplementary phosphate dosing to increase the dose from about 1 mg/l to 2 mg/l, to try to reduce the effluent lead concentrations.

From the feed tank, the water was pumped to Pipes 1, 2, 3 and 4 (control) by a PLC-controlled centrifugal pump.

### A2.2.2 Soft water

The soft water used in the trials was tankered every 3-4 weeks from United Utilities. Water was delivered to a 28 $m^3$ black polythene bulk storage tank from where it was pumped to a 0.6 $m^3$ black polythene feed tank, with the flow controlled by a brass-bodied float valve.

Water was continually recycled to the bulk storage tank to maintain homogeneity and prevent anaerobic conditions. Sodium hypochlorite solution was dosed to the feed tank to maintain a free chlorine residual of about 0.05-0.10 mg/l.

From the feed tank, the water was pumped to Pipes 5 (control), 6, 7 and 8 by a PLC-controlled centrifugal pump.