SAMPLING OF DRINKING WATER TO ESTIMATE POPULATION EXPOSURE TO LEAD

A paper produced for the DOE Lead in Potable Water Sub-Committee

R. J. Bailey

September 1981

188-M

EXTERNAL CIRCULATION: DOE Lead in Potable Water Sub-Committee - 30 copies

DOE Nominated Officer - 1 copy

INTERNAL CIRCULATION: Director, appropriate Assistant Director and Manager plus 4 copies to Divisional Scientific Staff
SAMPLING OF DRINKING WATER TO ESTIMATE POPULATION EXPOSURE TO LEAD

A paper produced for the DOE Lead in Potable Water Sub-Committee

R J Bailey

September 1981

188-M

EXTERNAL CIRCULATION: DOE Lead in Potable Water Sub-Committee - 30 copies

DOE Nominated Officer - 1 copy

INTERNAL CIRCULATION: Director, appropriate Assistant Director and Manager plus 4 copies to Divisional Scientific Staff

WRC ENVIRONMENTAL PROTECTION
Medmenham Laboratory, Henley Road,
Medmenham, P.O. Box 16, Marlow, Bucks, SL7 2HD
Tel: Hambleden (Bucks) (049 166) 531
SUMMARY

As part of the continuing programme of research into the health aspects of trace metals in drinking water the Water Research Centre, under contract to the Department of the Environment, is investigating the problems of sampling for lead in tap-water.

The aim of the work is to develop a reliable, practicable and economical procedure for sampling drinking water in such a way that the water-lead exposure of typical inhabitants of a particular house or water supply zone can be estimated with known statistical tolerance.

Existing data on household water use patterns and stagnation curves is described. Manually recorded data on water use patterns is compared with a new body of better data recorded automatically in several houses using water meters, with electrical output, coupled with data-loggers.

The report supports the concept of fixed stagnation time sampling as a way of estimating exposure to lead in drinking water, but further work is needed to justify this approach.

Proposals are put forward:-

i) To conduct a national survey to derive an estimate of the UK population distribution of household inter-use stagnation times.

ii) To carry out further experiments, using automatic samplers, to study stagnation curves in occupied houses.
CONTENTS

SUMMARY

1. INTRODUCTION  1

2. WATER USE PATTERNS  2
   2.1. EXISTING DATA  2
   2.2. NEW DATA  7

3. STAGNATION CURVES  7
   3.1. EXISTING DATA  7
   3.2. NEW DATA  8

4. ESTIMATING POPULATION EXPOSURE - SAMPLING METHODS  9

5. CONCLUSIONS  10

ACKNOWLEDGEMENT  10
1. INTRODUCTION

As part of our research into the health aspects of inorganic constituents in drinking water the Water Research Centre, under contract to the Department of the Environment, is undertaking further investigations into the problems of sampling for water-lead. The objective of this work is:-

"To develop a reliable, practicable and economical procedure for sampling household drinking water supplies in such a way that the water-lead exposure (defined as the mean lead intake from drinking water) of typical inhabitants of a particular house or water supply zone can be estimated with known statistical tolerance".

Such a procedure could:-

i) Aid the interpretation of guide levels or standards for acceptable lead concentrations in drinking water; the main weakness of existing guidelines and standards is their lack of specificity about the type of sample to which the concentration limits are intended to apply,

ii) Improve our knowledge of the contribution which drinking water makes to the overall exposure of population groups to lead in the environment,

iii) Be used for water-lead sampling in conjunction with medical measurements on individuals in medical surveys which could not afford the expense and inconvenience of proportional composite sampling.

This paper outlines the approach which we are taking to this work and expands the ideas which were presented to the Committee in a previous paper (LPWSC/81/1) at their meeting in February 1981.

The general approach which we are following is to separate and quantify the two main components of sampling variation:-

a) The patterns of intermittent flow of water in the service pipe and household plumbing controlled by the behaviour of the consumer.

b) The rate of build-up of water-lead concentration with stagnation time, controlled by the behaviour of the service pipe and household plumbing.
The rest of this paper discusses the available data on a) and b) above and a programme of work for obtaining further information.

2. WATER USE PATTERNS

2.1. EXISTING DATA

At present, data on domestic water use patterns are scant. The most important information we would like to obtain from a study of household water use patterns is the distribution of the time intervals between successive draws of water through the service pipe. In the earlier phase of this project no data was available on the flow patterns of water in consumer service pipes from which these 'inter-use' times could be derived. We therefore decided, in the preliminary development of the work, to obtain these data by asking the occupants of several households to keep diary records at all outlets of the times of all water uses in their homes over a period of 7 days. By placing all the recorded times in chronological sequence and subtracting successive times, a distribution of inter-use times for each house was obtained. However, the information obtained in this way was limited in its usefulness for the following reasons:-

i) The small sample of households in this preliminary survey is probably not representative of the wide range of UK household sizes and types.

ii) Diary records are possibly subject to bias and omissions due to human error.

iii) No satisfactory correction could be made to allow for the re-filling of the storage tank after the recorded use-time of those outlets supplied from it. (Generally, in the South of England all outlets except the kitchen cold tap are supplied from storage).

If the assumption is made that daytime water uses are independent and occur randomly throughout the day, then it can be shown that the time intervals between successive uses have a negative exponential distribution. The diary data obtained from 7 households supported this hypothesis. However, the inter-use time distributions of both large and small households tended to diverge from the exponential distribution because of the greater proportion of short and long inter-use times respectively. A more flexible form of the exponential distribution (the two-parameter Weibull distribution) gave a much better fit
to the data than the exponential distribution in these more extreme cases. Table 1 gives the mean inter-use stagnation times and other summary statistics for the 7 households in which the weekly diaries were kept.

Table 1. Summary statistics for the distributions of inter-use stagnation times for 7 households where diary records of water use were kept

<table>
<thead>
<tr>
<th>Household number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of persons in household</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Minimum stagnation time (minutes)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Maximum stagnation time (minutes)</td>
<td>263</td>
<td>294</td>
<td>240</td>
<td>245</td>
<td>262</td>
<td>185</td>
<td>250</td>
</tr>
<tr>
<td>Mean stagnation time (minutes)</td>
<td>34.3</td>
<td>25.6</td>
<td>23.5</td>
<td>30.7</td>
<td>30.0</td>
<td>36.0</td>
<td>39.5</td>
</tr>
<tr>
<td>Median stagnation time (minutes)</td>
<td>21.0</td>
<td>12.0</td>
<td>13.0</td>
<td>15.5</td>
<td>18.5</td>
<td>25.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>21.0</td>
<td>39.7</td>
<td>29.7</td>
<td>35.5</td>
<td>37.2</td>
<td>32.9</td>
<td>59.6</td>
</tr>
<tr>
<td>Number of observations</td>
<td>197</td>
<td>283</td>
<td>301</td>
<td>258</td>
<td>212</td>
<td>245</td>
<td>142</td>
</tr>
</tbody>
</table>

Recently a new body of better data on household inter-use time intervals has become available. These data were collected by the WRC as part of an independent project concerned with household water metering. Existing external meters at 27 domestic premises in Oxford were replaced with Kent PSM meters modified for electrical output. The meter output (c 80 pulses ò 1 litre) was logged every 5 seconds over a single 24 hour period. Of the 27 houses in this survey, 7 sets of data were unusable owing to equipment failure. Results from the remaining 20 houses were analysed to obtain both the inter-use stagnation times and the volumes of each separate draw through the service pipe. Figures 1 to 4 show the frequency distribution of inter-use stagnation times for the four main occupancy clusters: 2 adults only; 2 adults + 1 child; 2 adults + 2 children and "large" families (more than 2 adults with 1 or more children). Table 2 gives the mean inter-use times for individual houses.
Frequency distributions for the Oxford inter-use stagnation times (Weibull probability distribution)

Figure 1 - 2 adults

Figure 2 - 2 adults + 1 child
Frequency distributions for the Oxford inter-use
station times (Weibull probability distribution)

Figure 3 - 2 adults + 2 children

Figure 4 - 2 adults + 1 child
Table 2

Mean inter-use stagnation times for the Oxford data

<table>
<thead>
<tr>
<th></th>
<th>2 adults</th>
<th>2 adults+ 1 child</th>
<th>2 adults+ 2 children</th>
<th>&gt;2 adults+ 1 or more children</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean (mins)</td>
<td>n</td>
<td>mean (mins)</td>
<td>n</td>
<td>mean (mins)</td>
</tr>
<tr>
<td>19.4</td>
<td>42</td>
<td>21.5</td>
<td>41</td>
<td>15.5</td>
</tr>
<tr>
<td>54.3</td>
<td>8</td>
<td>9.2</td>
<td>33</td>
<td>32.7</td>
</tr>
<tr>
<td>17.9</td>
<td>39</td>
<td>12.0</td>
<td>70</td>
<td>26.6</td>
</tr>
<tr>
<td>32.5</td>
<td>13</td>
<td>14.2</td>
<td>43</td>
<td>45.8</td>
</tr>
<tr>
<td>22.3</td>
<td>24</td>
<td>26.6</td>
<td>24</td>
<td>7.8</td>
</tr>
<tr>
<td>19.7</td>
<td>43</td>
<td>17.7</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

Weighted mean inter-use stagnation times for the above occupancy categories:

- 2 adults: 22.2 mins, 196 observations
- 2 adults + 1 child: 14.0 mins, 144 observations
- 2 adults + 2 children: 19.8 mins, 196 observations
- >2 adults + >1 child: 13.3 mins, 260 observations
together with the weighted mean inter-use time for each occupancy cluster.

2.2. NEW DATA

Data from the 'Oxford' survey on inter-use stagnation times is obviously a great improvement on the previous diary data but since each house was only monitored for 24 hours no account could be taken of between-day variation. In addition, the survey was limited to just one relatively small area in one town and so does not take into account geographical variation in water use patterns. It is therefore proposed to undertake a national survey to derive an estimate of the UK population distribution of household inter-use times; in other words, an estimate for the "typical inhabitants" of the project objective (Section 1). Using the Oxford data to obtain a crude estimate of the between-house variation in mean inter-use times, it has been calculated that a sample of about 100 houses will be required to estimate the UK population mean inter-use stagnation time to within ± 10% at the 99% confidence level. Water use patterns will be monitored over a 7 day period at each house using electrical recording equipment similar to that used in the Oxford survey. An important modification which we hope to include is a consumer-operated button placed by the kitchen cold tap which will flag the uses drawn for drinking purposes. This will test the validity of the assumption that the distribution of stagnation intervals before drinking is the same as the distribution of all random daytime stagnation intervals. In addition, since information on the volume of each draw through the service pipe can be obtained from the data, it will be possible to construct a frequency distribution of drinking use volumes to improve the accuracy of estimates of lead intake. The most important criteria in the design of this national survey are that the sample of houses chosen should be representative of household size and socio-economic classification; the timing of the survey must take account of seasonal variation in water use patterns. The assistance of a market research organisation may be sought in selecting the sample houses to ensure that a representative stratified sample is obtained. Installation of water meters will be undertaken by WRC in co-operation with the Water Authorities and Regional Councils.

3. STAGNATION CURVES

3.1. EXISTING DATA

As with domestic water use patterns data, information on the rate of build up of water-lead concentration with stagnation time is limited. This is because of the extensive time and manpower required to obtain each curve.
Currently the WRC has obtained full stagnation curves for lead pipes at only three different locations covering two water quality areas and very few curves are available from other sources. A justifiable criticism of these previous stagnation curves is that because they had to be obtained at unoccupied premises, such as Water Authority pumping stations, they were not representative of the conditions existing in frequently used domestic service pipes. Further data is therefore required:

i) To show how different types of stagnation curves vary with pipe diameter, length, the presence of bi-metallic junctions and water quality.

ii) To assess both the long and short-term reproducibility of stagnation curves on the same pipe.

3.2. NEW DATA

It is for the reasons given in Section 3.1. that the WRC is now proposing to conduct further experiments on stagnation curves in occupied domestic premises using automatic sampling machines* to take samples during the night. Initially, two sampling machines will be purchased and used to sample intensively in defined water supply zones to estimate the within-house and between-house variability in stagnation curves. Priority will be given to areas whose problems with lead in drinking water have been well established and where the water quality is fairly constant.

Because of the effort and expense involved, the number of houses sampled will necessarily be much smaller than in the water use patterns survey. The aim here is however different. While with the inter-use stagnation times we want to obtain the probability distribution for the population of UK households, with stagnation curves, we need only show the range of different curves which can arise from different plumbing configurations and water types, to ensure that our sampling proposals are capable of coping satisfactorily with all types of stagnation curves that can arise in practice.

* Epic Products EPS1020 automatic potable water sampler, originally designed to the specification of Severn-Trent Water Authority (Tame Division) is currently being assessed for this purpose, The basic machine would be modified to accept a pre-programmed sequence of different stagnation times to produce a stagnation curve.
4. **ESTIMATING POPULATION EXPOSURE - SAMPLING METHODS**

The new information resulting from the work described in Sections 2.2 and 3.2 will provide a firmer basis on which to design a sampling procedure to meet our original objective. The procedure which we envisage at present is likely to be based on an assumption of a 'typical' pattern of water use which, when combined with an approximate estimate of the stagnation curve for a particular house, produces an estimate of the mean concentration of lead in water drawn for drinking purposes. If this mean concentration is then multiplied by the mean volume of tap-water consumed at home by the UK population we can calculate the mean intake of lead from drinking water for 'typical' inhabitants of the house in question. In practice, since it is clearly uneconomical to produce a complete stagnation curve for each house being investigated, the pertinent features of the stagnation curve have to be approximated from a small number of samples. The simplest possibility, and the one which the WRC will evaluate first, is to use a single fixed stagnation time sample. This kind of sample has already been employed successfully for other reasons in the case studies to monitor the effects of water treatment on tap-water lead levels. However, from the point of view of assessing exposure, there are a number of outstanding questions:

i) How feasible is it to predict the mean drinking water lead concentration for a particular household from the mean concentration in samples taken at a fixed stagnation time?

ii) How many fixed stagnation samples are needed to achieve the desired level of statistical reliability? Is a single sample sufficient? If not, then we must decide whether it would be better to take further samples at the same stagnation time or try to improve the characterisation of the stagnation curve by taking samples at different stagnation times.

iii) What is the appropriate stagnation time (or combination of times) to use?

iv) Should information about the geometry and materials (including the presence of bi-metal junctions) in the service pipe and plumbing system be incorporated into the sampling procedure?

* The mean daily volume of water consumed at home has been estimated as approximately 1 litre per head for the UK population (WRC Technical Report TR 137, 1980).
The work outlined in this report is designed to answer these questions and to provide background information so that a range of different sampling procedures can be compared.

5. CONCLUSIONS

i) This report presents information on household inter-use stagnation times which is available at the present time from small-scale surveys.

ii) The report supports the concept of fixed stagnation time sampling as a way of estimating average lead intake, but further work is needed to justify this approach.

iii) Proposals are put forward to conduct a national survey to derive an estimate of the UK population distribution of household inter-use stagnation times. We also propose to carry out further experiments, using automatic sampling techniques, to study stagnation curves in occupied houses.

ACKNOWLEDGEMENT

The work in this report was undertaken by the Water Research Centre in part fulfilment of a research contract with the Department of the Environment.
WATER RESEARCH CENTRE

REGISTERED OFFICE: 9 Dartmouth Street,
London SW1H 9BL
Tel: 01-222 0494.

WRC ENVIRONMENTAL PROTECTION,
Medmenham Laboratory: Henley Road,
Medmenham, P.O. Box 16, Marlow, Bucks, SL7 2HD
Tel: Hambleden (Bucks) (049 166) 531.

WRC PROCESS EVALUATION,
Stevenage Laboratory, Elder Way,
Stevenage, Herts, SG1 1TH
Tel: Stevenage (0438) 2444.

COLESHILL EXPERIMENTAL PLANT,
Lichfield Road,
Birmingham, B46 1NX
Tel: 021-749 1342.

WRC ENGINEERING CENTRE,
Empire House,
Clarence Street,
Swindon, Wilts, SN1 2LL
Tel: Swindon (0793) 694055.

SCOTTISH OFFICE,
1, Snowdon Place,
Stirling, FK8 2HN
Tel: Stirling (0786) 71580.